Diagnostic Feasibility Study of Lake Waubee Kosciusko Co., Indiana

Final Report

to the

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ABSTRACT

Lake Waubee is a glacial kettle lake in northcentral Indiana, with a surface area of 76 ha. and a volume of 6.017×10^6 m^3. Limnological studies conducted from September, 1980, through August, 1981, allowed formulation of hydrologic and nutrient budgets. Mass water loading to the lake was 8.331×10^6 m^3 y^{-1}, and resulted in a hydraulic residence time, t_w, of 0.72 years. Approximately 90% of the water entered the system via streamflow input. Measured areal phosphorus and nitrogen loadings were 0.77 and 106.4 g m^{-2} y^{-1}, respectively. Streamflow input of nutrients contributed 69.3% of the P and 96.3% of the N loading. Septic input and internal loading of nutrients from the sediments was minimal. Lake Waubee retained 70% of the P and 67% of the N entering the system. The mean annual P concentration was 30 µg l^{-1}, indicative of a moderate degree of eutrophy. Management strategies focus on reducing the streamflow nutrient inputs.

CONCLUSIONS

1. Lake Waubee is a mesotrophic to mesoeutrophic lake, with drastically improved water quality during the last several years.

2. Annually, approximately 90% of the water enters the Lake Waubee system from Hammond and Felkner Ditches.

3. Hammond and Felkner Ditches supply about equal amounts of phosphorus to the lake, and collectively contribute 69.3% of the annual mass phosphorus loading to Lake Waubee.

4. Hammond Ditch supplies about twice as much nitrogen as Felkner Ditch, and together these streamflow sources account for 96.3% of the annual mass nitrogen loading to Lake Waubee.

5. Major phosphorus and nitrogen sources are diffuse, nonpoint agricultural lands which dominate the watershed of Lake Waubee.

6. Plant communities in Lake Waubee are phosphorus limited.

7. Macrophyte and algal communities in Lake Waubee are moderate, and do not present serious recreational problems.

8. Bacteriological analysis of Lake Waubee indicate that the entire lake is safe for public use.

9. Septic systems do not appear to be negatively impacting the lake.

10. Sediments are a net sink for phosphorus, and internal phosphorus loading is minimal.

11. Management strategies focus on cosmetic control of macrophytes (i.e. weed barriers, mechanical harvesting, and herbicides), reducing phosphorus inputs (no-till agriculture, grassed waterways), and preventing future problems (septic system maintenance, wetland preservation, and development regulation).

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I. INTRODUCTION

Lake Waubee was selected for a diagnostic feasibility study leading to a lake restoration-management effort because of its eutrophic state and concurrent problems for recreational uses. Furthermore, public support among lake residents for this project was strong, and the lake was given high priority for such a study by the Indiana State Board of Health. In fall, 1980, following approval and funding by the U.S. Environmental Protection Agency, the project was initiated by Ball State University. Intensive tributary and in-lake monitoring was conducted through August, 1981. This sampling allowed for the development of extensive nutrient budgets for the lake. Using the information in these budgets, a management plan for restoring the water quality of Lake Waubee has been developed. This plan has been reviewed by lake residents and its initiation awaits funding by state and/or federal agencies.

II. PHYSICAL CHARACTERISTICS

A. Morphometric Measurements

Lake Waubee is a relatively small lake of 75.85 hectares (187.4 acres) located in Kosciusko County, Indiana (Fig. 1). Morphometric information for the lake was obtained from a 1957 USGS bathymetric map of the lake (Fig. 2). Using the methods of Wetzel and Likens (1979), morphometric parameters were calculated by planimetry and these are summarized in Table 1. Hypsographic and depth-volume curves were also plotted, and these are shown in Figure 3.

Lake Waubee has a maximum depth of 15.7 m and a mean depth of 7.93 m. The lake has a relative depth of 1.59%, which means that the lake is about average in its resistance to wind mixing. The shoreline development, D_L, of 1.67 indicates that the potential for littoral communities is not exceedingly large.

B. Tributaries

Lake Waubee receives input from two streams, Hammond and Felkner Ditches (Figs. 2, 4). Felkner Ditch enters through a shallow arm in the southeast corner of the lake. It originates at the outflow of waste holding ponds for the Maple Leaf Duck Farm and flows about three stream miles through marshy wet-lands before it enters the lake. Throughout its entire length, the stream is fed by hillside springs which drain the surrounding farmland. Large erosional gulleys indicate areas where runoff from farm fields enters the stream.

Hammond Ditch enters the eastern corner of the lake by the Camp Mac church camp facilities. It originates several stream miles east of Lake

Waubee at the outflow of Dewart Lake. It drains several large farm fields and pastures before entering a marsh-woodland area about 0.5 to 1.0 miles upstream of the lake.

Lake Waubee is drained by a single outflow in the northern portion of the lake. This stream has flowed continuously since the beginning of this study (October, 1980).

C. Lake Watershed

The size of the Lake Waubee watershed is 3.6678×10^7 m^2. The land usage of the watershed falls into only two major categories, agricultural land and forested land. Residential, urban, and other uses account for less than 1% of the watershed area. The dominant usage of the watershed land (>92%) is for agricultural purposes and the major crop is corn. About 7% of the land is forested.

The agricultural practices of the farmers in the watershed are similar to most farming techniques used in the mid-west. Fields are often plowed in late fall after harvest and allowed to remain barren all winter. Heavy fertilizer applications of phosphorus and ammonia are made prior to spring planting. Herbicides are applied at or soon after planting.

Fig. 1. Location of Lake Waubee.

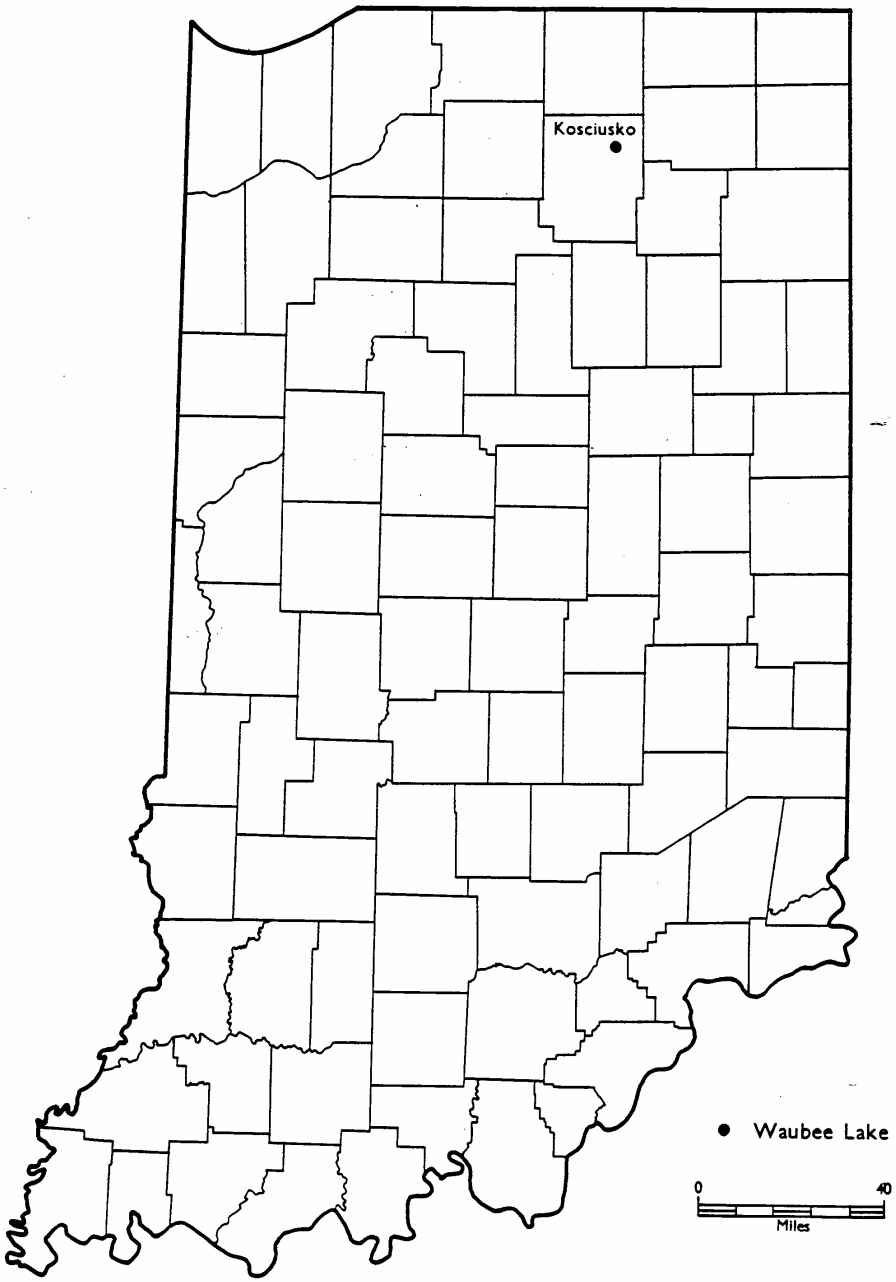

Kosciusko
Waubee Lake
0
40
Miles

Fig. 2. Bathymetric map of Lake Waubee (after U.S.G.S., 1957). Contours are in 5 ft intervals.

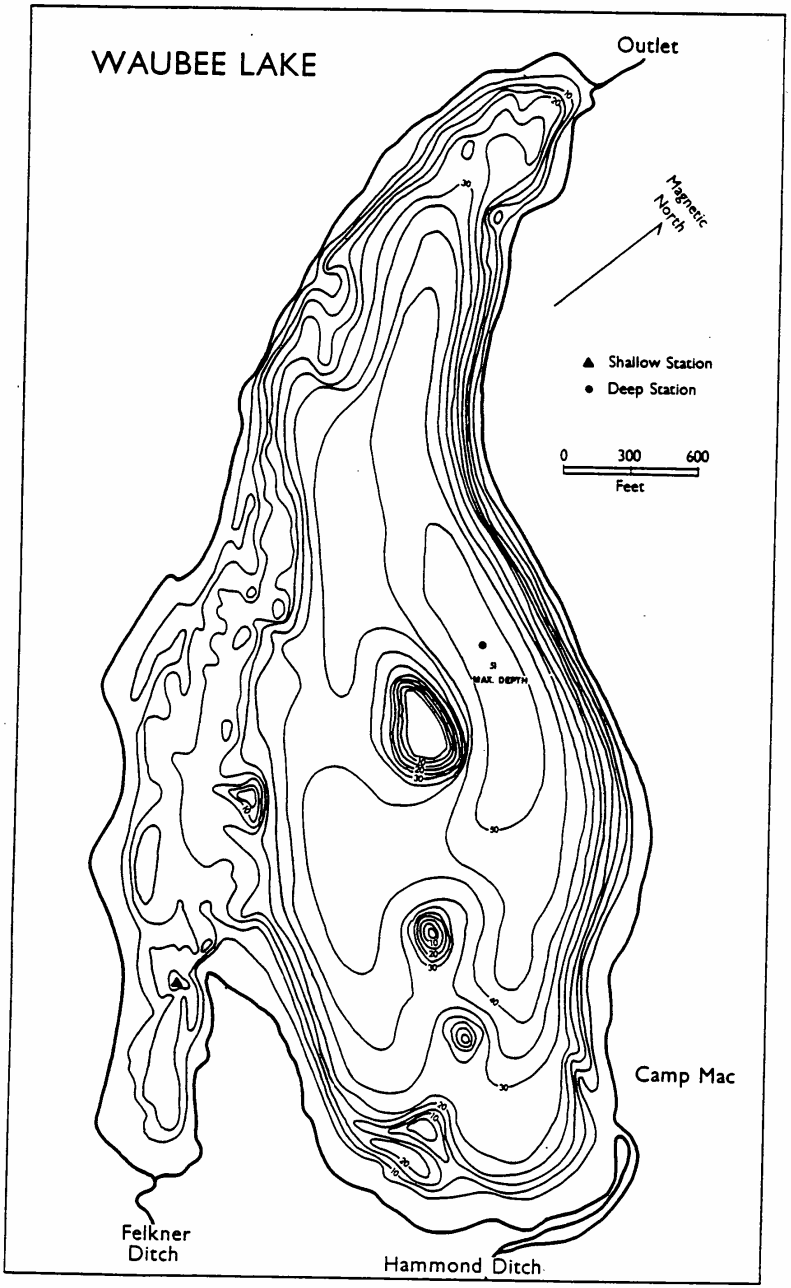

WAUBEE LAKE
Outlet
Magnetic North
Shallow Station
Deep Station
0 300 600
Feet
MAX. DEPTH
Camp Mac
Felkner Ditch
Hammond Ditch

Fig. 3. Hypsographic (A) and depth-volume (B) curves for Lake Waubee.

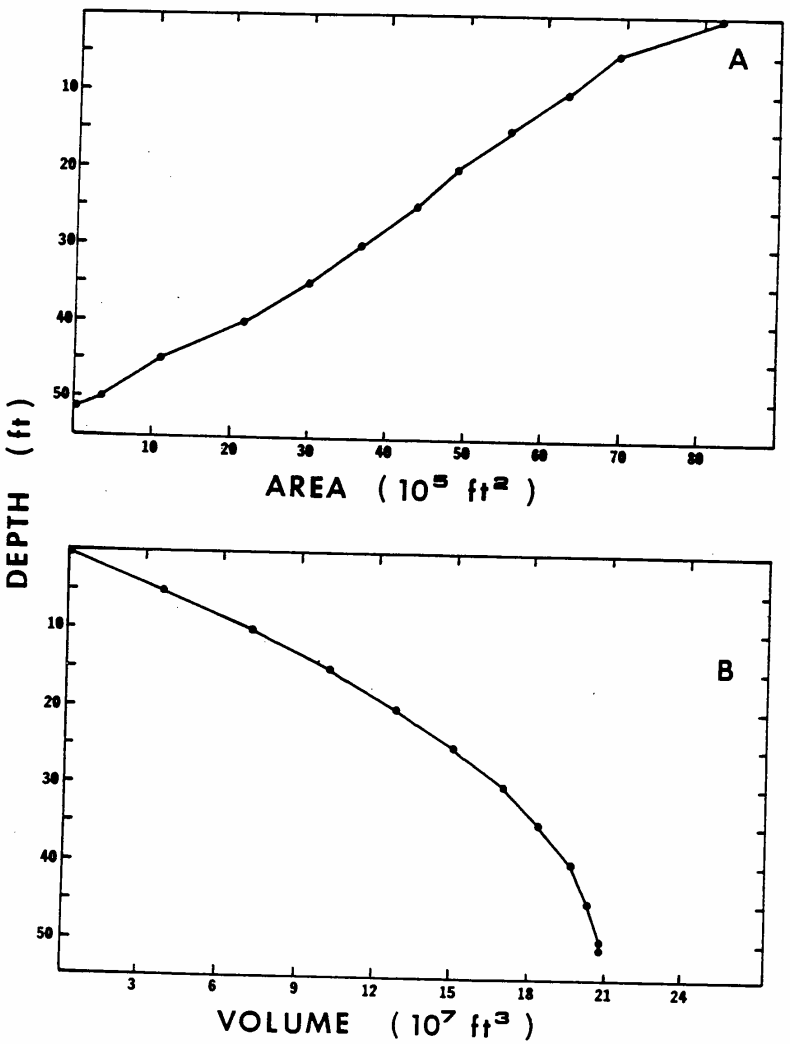

A
B
DEPTH (ft)
10
20
30
40
50
10
20
30
40
50
60
70
80
AREA (10^5 ft^2)
3
6
9
12
15
18
21
24
VOLUME (10^7 ft^3)

Fig. 4. Diagrammatic view of Lake Waubee watershed, showing tributary sampling stations.

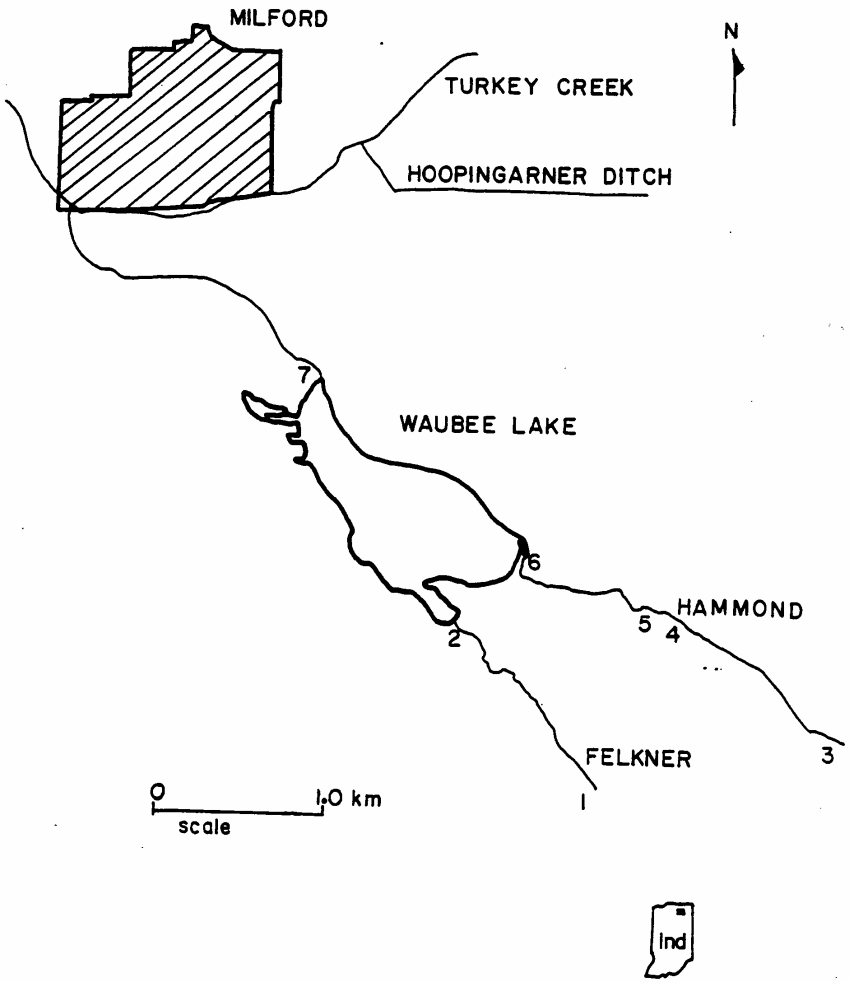

MILFORD
N
TURKEY CREEK
HOOPINGARNER DITCH
7
WAUBEE LAKE
6
HAMMOND
5
4
2
3
FELKNER
1
0
1.0 km
scale
Ind

TABLE 1.

Morphometric Parameters for Lake Waubee

Parameter	Symbol	Value
Surface area	A_o	75.85 ha
Volume	V	6,017,361 m^3
Shoreline length	L	5157.2 m
Shoreline development index	D_L	1.67
Volume development index	D_V	1.52
Maximum effective length	l	1595.5 m
Maximum breadth	b	754.9 m
Mean breadth	$\bar{b}$	474.3 m
Maximum depth	Z_m	15.7 m
Mean depth	$\bar{Z}$	7.93 m
Relative depth	Z_r	1.597%
Center of gravity	Z_g	4.88 m

III. METHODS

A. Tributary and outlet monitoring

The two inlets and single outlet of Lake Waubee were monitored from November, 1980, through August, 1981. The outlet stream was sampled at a single location about 10 m downstream from the lake (Site 7). Felkner Ditch was sampled at two locations: the first, Site 1, is located just below the outflow of the Maple Leaf Duck Plant's waste control ponds and the second, Site 2, is located just before the stream enters the lake. Hammond Ditch was sampled at four locations. The first, Site 3, is positioned about 30 m downstream from where the stream originates at Dewart Lake; the second, Site 4, is located just upstream from Rink's farm in a pasture area; the third, Site 5, is situated in a wooded area at Rink's farm; and the fourth, Site 6, is located where the ditch enters the lake in a marshy area near Camp Mac. The position of each tributary sampling site is shown in Figure 4. Because no significant differences in any of the parameters were noted between Sites 4 and 5, only the data from Site 5 is reported.

1. Chemical variables

Water samples for chemical analyses were collected at all tributary sampling locations (Sites 1-7) during the sampling period. Water samples were analyzed for total P, soluble-reactive P, NH_3, NO_2, NO_3, organic N, silica, alkalinity, total and particulate organic matter, and total and organic residue. Samples were collected in 1-ℓ Nalgene bottles, preserved with two ml of 10.8 N H_2SO_4, (for appropriate parameters), placed in an ice chest, and returned to the laboratory for analysis. Measure-

ments of soluble reactive P were made immediately upon return to the laboratory; all other nutrient assays were completed within 24-48 hours after sample collection. Sequential samplers (Isco Model 1680) were placed at Sites 2 and 5 to obtain daily integrated water samples (a sample was collected every 6 hours); these were collected at biweekly intervals through June and July and returned to the laboratory. Analytical procedures for determinations of the chemical variables outlined above were identical to the procedures used in the lake monitoring of chemical variables. These procedures are outlined in detail in Appendix I.

2. Streamflow

The volume of water carried in each tributary stream and the outlet was determined from measurements of water height. At sampling Sites 2, 5, and 7 lacquered meter sticks were mounted in the streams to serve as staff gauges, and the height of the stream was recorded several times weekly by local residents. Beginning in April, 1981, sampling Sites 2, 5, and 7 were monitored continuously using Leopold Stevens Type F water level recorders. The water level recorders were enclosed in weather- and vandal-proof boxes and mounted in stilling wells consisting of culvert pipe 30.5 cm in diameter. Continuous water level readings were recorded on eight-day charts and calibrated to water level using the lacquered meter stick staff gauges.

On several dates throughout the year, corresponding to various water level heights, stream flow measurements were taken at Sites 2, 5, and 7 using a Marsh-McBirney Model 201 Flow Meter. A smooth-bottomed area of the stream was selected and flow measurements

were made at 60% of the water depth for each 0.25 m width interval across the stream. Total stream flow (as $m^3 s^{-1}$) was calculated according to the mid-section method of Nemerow (1974) using a computer program written by H. Senft (Appendix I).

B. Lake monitoring

In-lake monitoring of Lake Waubee commenced in late November, 1980, and continued through August, 1981. The lake was sampled monthly from November to March. However, unsafe ice conditions on the lake in December and February prevented sampling during those months. Beginning in early April and continuing through August, the lake was sampled biweekly. Several physical, chemical and biological variables were measured on each sampling date. Water samples for chemical analyses were collected in 1-ℓ Nalgene bottles, preserved with two ml of 10.8 N H_2SO_4 (appropriate parameters only), placed in an ice chest, and returned to the laboratory for analysis. Selected water samples for each chemical variable were triplicated to obtain estimates of precision. Methods of analysis for each of these variables are discussed individually below.

1. Physical variables

Temperature

In-situ temperature profiles were obtained at 0.5 m intervals at both the deep and shallow stations using a Hydrolab 4041 probe. On occasion, a YSI telethermometer was used in place of the Hydrolab 4041 probe.

Conductivity

In-situ conductivity measurements were made using a Hydrolab 4041 probe. Readings were taken at 0.5 m intervals from the surface to the bottom at both in-lake stations.

Turbidity

Depth profiles of turbidity were obtained at both the deep and shallow water stations of Lake Waubee. Measurements were made using an H. F. Instruments Model DRT-15 Series A turbidameter on water samples which were returned to the laboratory, warmed, and shaken.

Secchi Disk

On each sampling date, secchi disk readings were obtained at both the shallow and deep water lake stations. A 20 cm diameter standard secchi disk was lowered into the lake until it became invisible and then raised slowly until it reappeared; this depth was noted and recorded as the secchi disk depth.

Light Attenuation

The attenuation of photosynthetically active radiation (Ph.A.R.) in Lake Waubee was measured using a LICOR Model LI-186A quantum sensor fitted with a 4π spherical collector. Depth profiles of light intensity were taken by lowering the quantum sensor through the water column and obtaining readings at discrete 0.25 or 0.5 m intervals. Attenuation coefficients were calculated according to Lambert-Beers relationship

$$I_{z_j} = I_{z_i} \; e^{-nz_{ij}} \qquad 1)$$

where

I_{z_j} = intensity of depth z_j (μEin $m^{-2}s^{-1}$)

I_{z_i} = intensity at depth z_i (μEin $m^{-2}s^{-1}$)

n = total attenuation coefficient (m^{-1})

z_{ij} = depth interval z_i to z_j (m)

Total attenuation coefficients, n, were partitioned into two components: a portion due to chlorophyll *a* (n_c) and a portion due to all other factors (n_w). Equation 1 was thus rewritten as:

$$I_{z_j} = I_{z_i} \; e^{-(n_c C + n_w) z_{ij}} \qquad 2)$$

where C is the chlorophyll *a* concentration of the water (mg m^{-3}) and n_c is a constant ($0.016\ m^3 (mg\ chl\ a)^{-1}$).

Replicate or triplicate profiles were averaged to calculate attenuation coefficients. All measurements were taken under constant light conditions.

2. Chemical variables

pH

In situ profiles of pH were obtained at 0.5 m depth intervals at both the deep and shallow stations using a Hydrolab 4041 probe. The probe was calibrated before and after each use according to manufacturer specifications.

Dissolved oxygen

In situ profiles of dissolved oxygen were obtained at 0.5 m depth intervals at both the deep and shallow stations using a Hydrolab 4041 probe. This probe was calibrated before and after each use according to manufacturer specifications.

Phosphorus

Total

Laboratory determinations of total phosphorus were made on acidified water samples. A 50 ml aliquot was analyzed using the persulfate digestion procedure of Menzel and Corwin (1965) followed by the molybdate-blue spectrophotometric determination with ascorbic

acid as the reductant. Complete details are presented in Procedure 2b of Appendix I.

Soluble Reactive

Soluble reactive phosphorus measurements were made immediately upon return to the laboratory. Water samples were filtered through pre-rinsed 0.45 μ glass fiber filters (Gelman Type A/E). A 50 ml aliquot was analyzed spectrophotometrically using the ascorbic acid, molybdate-blue method. Details are outlined in Procedure 2c of Appendix I.

Nitrogen

Ammonia

Ammonia concentrations were determined in 50 ml aliquots of the acidified water sample using the method of Chaney and Marbock (1962). Following pH adjustment and reagent addition, spectrophotometric analysis of the sample was completed. Details of the method are given in Procedure 3 of Appendix I.

Nitrite

Nitrite was spectrophotometrically determined by the sulfanilamide diazotization technique of the E.P.A. (1979). A 25 ml subsample of acidified lake water was buffered and received the color reagent which reacted with nitrite to form an azo dye complex. Procedure 4 of Appendix I contains specific details of this method.

Nitrate

Spectrophotometric determination of nitrate was made by sulfanilamide diazotization following manual cadmium reduction of all nitrate to nitrite (E.P.A. 1979). Background nitrite levels were subtracted from this reading to give nitrate values. Consult Pro-

cedure 5 of Appendix I for this methodology.

Organic

Water samples collected for organic nitrogen analysis were acidified and cooled. Measurements of organic nitrogen were made using the persulfate digestion technique of Raveh and Avnimelech (1979). All nitrogen was oxidized by persulfate digestion, subsequently reduced with DeVarda's Alloy, and spectrophotometrically determined as ammonia using Solorzano's (1969) technique. Ammonia, nitrite, and nitrate background levels were subtracted to yield the organic nitrogen fraction. Specific methodology is listed in Procedure 6 of Appendix I.

Reactive Silica

Silica determinations were made on non-acidified water samples using a modified molybdosilicate method (A.P.H.A. 1971). Water samples were frozen at -20° C until analysis. After filtration with 0.45 μ Millipore HA filters and reagent addition, molybdosilicic acid concentrations were determined spectrophotometically in 50 ml aliquots of water. Details of this technique are presented in Procedure 7 of Appendix I.

Residue

Total

Total residue was determined gravimetrically on non-acidified water samples using the technique recommended by the E.P.A. (1979). A known volume of water was evaporated in a drying oven and the total residual weight was obtained. Procedure 8 of Appendix I outlines the method.

Volatile

The dessicated sample used for total residue analysis was ashed at 550° C for one hour. Weight loss upon combustion was determined and volatile residue was calculated (E.P.A. 1979). Refer to Procedure 8 of Appendix I for details.

Particulate Matter

Total

Total particulate matter was measured by filtering a known water volume (500-1000 ml) through a preweighed 0.45 µ glass fiber filter (Gelman Type A/E). Filters were dissicated in a drying oven at 101° C and reweighed. Total particulate matter was calculated by difference (Appendix I; Procedure 9).

Organic

Particulate organic matter was determined by measuring weight loss of the dried filter upon combustion at 550° C for one hour in a muffle furnace (Appendix I; Procedure 9).

Alkalinity

Total alkalinity was measured potentiometrically (Wetzel and Likens 1979). A 50 ml aliquot of non-acidified sample was titrated with 0.02 N sulfuric acid to a pH endpoint of 4.8. Total alkalinity was calculated from the volume of titrant used. A complete description of the method is contained in Procedure 10 of Appendix I.

3. Biological Variables

Bacteria

Water samples for bacteriological analyses were collected monthly from April through August at lake and tributary stations. All samples were collected aseptically from surface water in a 250 ml

sterile screw cap bottle. Samples were immediately cooled on ice for return to the laboratory for processing. In the laboratory, water samples were diluted according to Standard Methods for the Examination of Water and Wastewater (A.P.H.A. 1975) using 90 ml buffered water blanks. Appropriate dilutions were selected for lake and tributary water according to recommendations given in Microbiological Methods for Monitoring the Environment (E.P.A. 1978). Membrane filtration techniques were employed for determining total coliform, fecal coliform, and fecal streptococci in the water samples. The procedure followed was that outlined in Microbiological Methods for Monitoring the Environment (E.P.A. 1978). Samples were passed through sterile filters of 0.45 µm pore diameter (Gelman), placed in sterile petri dishes containing approximately 2 ml broth with a sterile absorbant pad of 3-5 ml agar. Duplicate samples were run of many dilutions.

Total coliform counts were determined by incubating membrane filters on sterile M-Endo broth (Difco) containing an absorbent pad. Plates were inverted, placed in a 35° C incubator and read after 24 hours. Those colonies showing a green metallic sheen under 10X magnification were considered positive. Those plates showing 20-80 colonies were chosen for determination of total coliform counts. Total coliforms were reported as numbers per 100 ml.

Fecal coliform counts were determined by incubating membrane filters on FC broth (Difco) for 24 hours at 44° C. Those plates showing 20-60 colonies were examined under 10X magnification to determine the fecal coliform count. Fecal coliforms were reported as numbers per 100 ml sample.

Fecal streptococci counts were determined using KF agar (Difco) and incubation of 48 hours, at 35° C. Filters showing between 20-100 pink to dark red colonies were chosen and counted under 10X magnification. Fecal streptococci were reported as numbers per 100 ml sample.

Verification of total coliform, fecal coliform, and fecal streptococci counts were performed on 10% of the total samples. Methods for verification of these counts are presented in Procedures 11a, 11b, and 11c of Appendix I.

The remaining bacteriological analysis conducted was that of the standard plate count. Appropriate dilutions of water samples were placed on Difco plate count agar (A.P.H.A. 1975) and distributed by the spread plate technique. Plates were incubated at 35° C for up to 7 days. Duplicate plates were run of the various dilutions. After 2 and 7 day incubation, plates were removed and those showing between 30-300 colonies were counted. Counts were reported as cells per ml sample.

Chlorophyll a

Chlorophyll a concentrations of lake water were determined spectrophotometrically from the SCOR/UNESCO equations of Strickland and Parsons (1965). Samples were filtered onto 0.45 μ glass-fiber filters, ground in 90% acetone, and extracted for 10 minutes in the dark. More complete details are presented in Procedure 12 of Appendix I.

Phytoplankton Communities

Depth profiles of algal samples were collected with a 6 ℓ Van Dorn bottle at biweekly intervals at both the deep and shallow

stations. Approximately 900 ml of lake water from each 1.5 m depth interval were preserved with 100 ml of F.A.A. solution in 1 ℓ sample bottles, stored on ice, and returned to the laboratory. Each 1 ℓ sample bottle was thoroughly shaken and exactly 250 ml was transferred to a 250 ml graduated cylinder. The remaining sample was measured and the total volume recorded. The 250 ml graduated cylinders were sealed with parafilm, labeled, and allowed to settle for four days. The samples were then concentrated to 50 ml by decanting the supernatent with a vacuum of 7 lbs Hg. The 50 ml concentrated samples were thoroughly mixed and transferred to labeled vials and kept refrigerated until counted.

Subsamples of the 50 ml concentrate were settled for 24 hours in settling chambers and counted at 100X to 320X on a Leitz Diavert Microscope. A minimum of 20-30 Whipple disc fields were counted to insure a large enough sample size. Counts were converted to numbers per ml using the formula:

$$\frac{\#\text{cells}}{\#\text{ WD}} \times \frac{\#\text{ WD}}{\text{SC}} \times \frac{\text{SC}}{\#\text{ml}} \times \frac{50\text{ ml}}{250\text{ ml}} \times 1.11 = \text{cells ml}^{-1}$$

where

#cells = total cells counted

#WD = total Whipple disk areas counted

SC = settling chamber area

#ml = volume of subsample settled

1.11 = correction factor for preservative dilution

Algae were grouped into phylogenetic classes for determination of percentage composition.

Cell volume estimations were made concurrently with cell counts by measuring algal cell dimensions, substituting these values into published formulae (Willen 1976), and computing average cell volumes. Calculated volumes were compared to published values for algae (Wetzel 1975) to check for agreement. Total cell volumes were calculated by multiplying the average cell volume of each species by the number of individuals per ml. Algae were again grouped into phylogenetic classes for determinations of composition by volume.

Primary Production

Primary productivity measurements using the light-dark bottle method of oxygen production were conducted twice on Lake Waubee during the summer. Lake water was collected at various depths with an opaque 6 ℓ Van Dorn bottle. At each depth, duplicate transparent and opaque 300 ml B.O.D. bottles were filled and suspended in the lake. A third set of duplicate bottles was also filled at each depth for determinations of initial oxygen concentrations; these bottles were 'fixed' immediately with Winkler Reagents. The suspended bottles were incubated for 3-5 hours during mid-day. Light extinction was measured three times throughout the experiment.

At the completion of the incubation period, the bottles were retrieved from the lake, fixed with Winkler Reagents, and stored in light-tight boxes for return to the laboratory. Once at the laboratory, the samples were acidified with concentrated H_2SO_4, and titrated with 0.025 N sodium thiosulfate using starch as an indicator according to the Winkler technique (A.P.H.A. 1975). The measured

oxygen content of each bottle (mg ℓ^{-1}) was used to determine gross photosynthesis (mg O_2 $\ell^{-1}h^{-1}$) according to the following formula:

$$\frac{L - D}{t}$$

where

L = light bottle oxygen concentration (mg ℓ^{-1})

D = dark bottle oxygen concentration (mg ℓ^{-1})

t = time (h^{-1})

These values were converted to carbon fixation, using the correction factors of 0.375 mg C per mg O_2 and an assimilation coefficient of 1.2 mg O_2 evolution per 1.0 mg C fixation.

Algal Assay

As an aid in determining the limiting nutrient to phytoplankton growth in Lake Waubee, the Environmental Protection Agency's Selenastrum capricornutum Printz Algal Assay Bottle Test was performed on water samples from Lake Waubee. Growth of the test alga, S. capricornutum, was evaluated under several nutrient conditions. Surface lake water was collected in plastic jugs and stored on ice until processing.

Upon return to the laboratory, the lake water was autoclaved and filtered through 0.45 µm Millipore filters. Numerous 250 ml flasks were filled with 150 ml of this water and stored for 24 hours to allow for CO_2 equilibration. Experimental treatments were run in triplicate: lake water alone, lake water + 0.05 mg ℓ^{-1} phosphorus, lake water + 1.0 mg ℓ^{-1} nitrate, and lake water + 0.05 mg ℓ^{-1} phosphorus + 1.0 mg ℓ^{-1} nitrate. Flasks filled with synthetic media served as controls for the experiment.

Algal inoculum was prepared by phosphorus starving a seven day old culture of S. capricornutum in phosphorus-free media for 24 hours. Enough of this culture was added to each experimental flask to yield a density of ca. 1000 cells ml^{-1}. The flasks were incubated for 14 days at a temperature of $24^{o}C \pm 1^{o}C$ and an illumination of 500 $\mu Ein\ m^{-2}\ s^{-1}$ on a 12:12 hour light-dark cycle. At the end of this time period, growth potential was determined by examining the maximum standing crop of each flask.

Biomass was measured gravimetrically by filtering measured aliquots of culture through pre-weighed 0.45 µm Millipore filters. The filters were then dryed at $100^{o}C$ for 24 hours, cooled, and weighed. Maximum standing crop for each treatment was calculated as $mg\ \ell^{-1}$ and recorded. Complete details of the experimental design are outlined in Procedure 13 of Appendix I.

Vascular Plants

The macrophyte community of Lake Waubee was sampled biweekly from May through August, 1981. Portions of the lake containing macrophytes were mapped and the area recorded. Samples were collected from each area using a white quadrat 0.50 m X 0.50 m. The quadrat was randomly thrown into the macrophyte beds and scuba divers then harvested by hand the above ground plant material within the quadrat. The vegetation was placed into a mesh diving bag, loosely rinsed of sediments, and transferred to a plastic bag for storage on ice during transportation to the laboratory.

In the laboratory, the samples were thoroughly rinsed with water. They were allowed to drain overnight. The samples were sorted by species and placed into pre-weighed aluminum pans to determine wet weight. They were then placed in a forced-air drying

oven for 48 hours at 90-101° C and weighed again for dry weight. The dried plant material was finely ground and subsamples were placed into pre-weighed containers for ignition at 500-550° C for one hour. After cooling in a dessicator, the ash weight was determined.

The measured weights were used to calculate macrophyte biomass in the lake on each sampling date. Total macrophyte biomass (wet, dry, and organic) in each portion of the lake was calculated based upon the sample weights and the surface area of that portion. The biomass values for all sections of the lake were summed and then divided by the total area of the lake supporting vascular plant growth to give a whole-lake, weighted average areal macrophyte biomass.

The concentrations of nitrogen and phosphorus in the macrophyte biomass were determined on each sampling date. Subsamples of dryed plant material were randomly selected for nutrient analyses. Phosphorus content was determined on persulfate digested samples (Wetzel and Likens 1979) using a molybdate-blue colormetric method. The nitrogen content of the samples was determined using the persulfate digestion technique of Raveh and Avnimelech (1979). The total nutrient pool incorporated in macrophyte biomass was calculated using the measured nutrient concentrations and the measure macrophyte biomass values. Procedure 14 of Appendix I provides a detailed outline of the macrophyte nutrient analyses used in this study.

Zooplankton

The zooplankton community of Lake Waubee was analyzed from

March, 1981 through August, 1981. Vertical sample hauls were taken bi-weekly using a 30 cm diameter plankton net of 80 μ mesh (#20 size) at both the deep and shallow stations. The samples were preserved in a 5% formalin solution immediately after collection and placed on ice for transport to the laboratory.

In the laboratory, the samples were allowed to settle for three days and then decanted to a volume 500 ml. A random subsample of the 500 ml sample was obtained with a stempel pipette and placed in a 5 ml Garnan counting tray for examination under a binocular microscope. Organisms were identified to species. Instar stages of copepods were also enumerated. Counts were converted to numbers per m^2 by dividing by the area of the plankton net.

C. Sediment Analysis

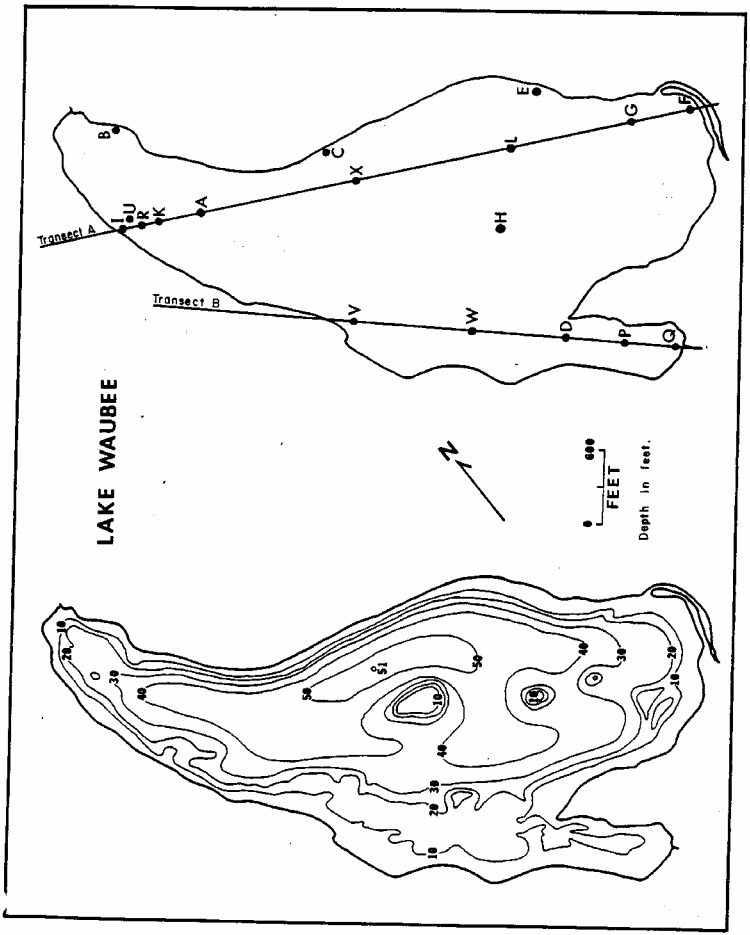
The sediments of Lake Waubee were analyzed for their phosphorus content in July, 1981. Eighteen samples were collected along two main transects across the length of the lake (Fig. 5). These collection sites covered the major profundal zones of the lake and represented sediments at different depths. Duplicate samples were collected at each site in acid-cleaned glass jars using scuba techniques. One jar was preserved with 10.8 N H_2SO_4 for phosphorus analyses while the other jar was reserved for gravimetric analysis. Samples were stored on ice until their return to the laboratory.

The phosphorus content of the acidified samples was divided into two portions. The first of these, interstitial water phosphorus, was determined from a 50 ml sample of interstitial water which was digested using a persulfate technique. The second portion, acid-nonlabile sediment bound phosphorus, was determined by performing a persulfate

digestion on the dried sediments. Both portions used the molybdate-blue spectrophotometric procedure for measuring phosphorus. More complete details are presented in Procedure 15 of Appendix I.

The moisture, inorganic, and organic content of the sediment samples was determined gravimetrically. Thirty to forty cm^3 of sediment were placed into pre-weighed crucibles and weighed to determine wet weight. The crucibles were then placed in a drying oven at 101° C for 24 hours and weighed again to determine dry weight. Finally, the samples were ashed at 550° C to determine the ash weight.

Fig. 5. Sediment sampling sites in Lake Waubee


LAKE WAUBEE
Transect A
Transect B
B
C
E
F
G
L
X
A
K
R
U
T
H
V
W
D
P
Q
FEET
Depth in feet.

IV. TRIBUTARY AND OUTLET MONITORING

A. Physical variables

Turbidity

The two tributary streams and outlet of Lake Waubee showed different seasonal variations in turbidity (Appendix II; Fig. 1). Outlet values were generally < 5 NTU, except during the summer months when they reached about 10 NTU. This is probably due to the flushing of algal cells through the outlet stream.

Turbidity values in Felkner Ditch fluctuated, and exceeded 25 NTU on different sampling dates at both sites. From June through August, turbidity values at both sites were similar to one another.

In Hammond Ditch, turbidity values never exceeded 25 NTU. All three sampling sites had similar values throughout much of the year.

B. Chemical variables

Phosphorus

Total

There are significant differences in concentrations of total phosphorus (total P) within the tributaries and among tributaries (Appendix II; Fig. 2). The concentration of total P leaving Lake Waubee through the outlet has remained fairly constant throughout the sampling period at about 15-25 $\mu g\ \ell^{-1}$. However, the concentration of total P in each inlet to the lake has fluctuated and generally remained well above 25 $\mu g\ \ell^{-1}$.

Felkner Ditch displays very apparent trends in total P concentration. Throughout the winter season (November through March), total P concentrations at the inlet of the lake (Site 2) are generally much larger than concentrations at the duck plant waste ponds (Site 1). This suggests that field runoff is important at this time of year. Beginning in April,

total P concentrations at Site 1 climb to extremely high levels (> 1000 μg ℓ^{-1}) during this time. This strongly suggests that the marshland between Sites 1 and 2 serves as a phosphorus trap during the summer months when plant growth is active. The lower values of total P at Site 1 before April are probably a reflection of dilution of the duck plant waste material by high precipitation and runoff.

Variations in the total P concentration of Hammond Ditch are much less pronounced than those in Felkner Ditch. With the exception of mid-February after snow-melt when concentrations reached 150 μg ℓ^{-1}, total P values in Hammond Ditch rarely exceeded 50 μg ℓ^{-1}. Concentrations at all three sites remained similar throughout the entire sampling period.

Soluble Reactive

Values of soluble reactive P (or "ortho" P) followed trends similar to total P values (Appendix II; Fig. 3). The outflow of Lake Waubee (Site 7) had constant soluble reactive P values of about 5 μg ℓ^{-1}. Fluctuations in the concentrations at this site are probably more related to varying precision in measurement than any other factor.

Soluble reactive P concentrations in Felkner Ditch showed sharp differences between Sites 1 and 2. At the outflow of the duck farm pond, Site 1, soluble reactive P concentrations remained constant at a low level of about 5-7 μg ℓ^{-1} from November through early June. At Site 2 (inlet), however, the concentrations fluctuated more and reached values in excess of 50 μg ℓ^{-1}. The temporal pattern closely resembled that for total P and this again suggests that field runoff plays an important role in the phosphorus dynamics of Felkner Ditch during this time period. In mid-June, soluble reactive P levels at Site 1 jumped to large values in excess of 2000 μg ℓ^{-1}. Values at Site 2, however, remained below 100 μg ℓ^{-1}

again indicating the importance of the growing vegetation in the marshland between the two sites as a phosphorus trap.

In Hammond Ditch, soluble reactive P concentrations remained very low (5-7 $\mu g\ \ell^{-1}$) at all three sites for most of the time period. However, a very sharp peak of ortho P was detected at Sites 5 and 6 during spring snow melt. This peak in concentration reached 105 $\mu g\ \ell^{-1}$. The absence of a strong peak at Site 3 (origin of Hammond Ditch) points out the importance of field runoff for this tributary also.

Nitrogen

Ammonia

Ammonia concentrations for each stream are shown in Figure 4 of Appendix II. The outlet of Lake Waubee had ammonia concentrations of less than 150 $\mu g\ \ell^{-1}$ throughout the entire nine month study period. Very little fluctuation in ammonia values occurred in the outlet; in general, though, ammonia values in the outlet during the winter months were higher than the summer months.

In Felkner Ditch, the ammonia concentrations show drastic differences. At the duck farm waste pond outflow (Site 1) ammonia concentrations are exceedingly high. They ranged from 200 to almost 3000 $\mu g\ \ell^{-1}$; these are anywhere from 10-100 times higher than the concentrations at the inlet to the lake (Site 2) which remained below 40 $\mu g\ \ell^{-1}$.

Ammonia values in Hammond Ditch showed almost no differences among any of the three sampling locations. All values remained below 60 $\mu g\ \ell^{-1}$ except for one sampling date in late March when values reached 200 $\mu g\ \ell^{-1}$.

Nitrite

Nitrite concentrations in the tributaries of Lake Waubee remained very low throughout the sampling period (Appendix II; Fig. 5). Concen-

trations of nitrite nitrogen generally remained below 30 μg ℓ^{-1} for almost the entire sampling period. However, during June, July, and August nitrite values increased to well above 50 μg ℓ^{-1} in Felkner Ditch. These nitrite values still represent only a minor fraction of the nitrogen loading entering and leaving the lake.

Nitrate

The nitrate concentrations in the tributaries of Lake Waubee vary from location to location (Appendix II; Fig. 6). The outlet of the lake, Site 7, had nitrate concentrations averaging about 0.75 mg ℓ^{-1} (750 μg ℓ^{-1}). There was little fluctuation in the concentration, except on January 23 when nitrate reached almost 4.0 mg ℓ^{-1}. It is not known if this value was due to a sampling error or not, but the value was far in excess of the other values reported for this location.

Nitrate concentrations in Felkner Ditch show some interesting trends. At the origin of the stream by the duck plant waste ponds (Site 1) nitrate levels were very low. Values remained below 1.0 mg ℓ^{-1} for the entire study period. In contrast, nitrate values at the inlet to the lake were very high and generally remained above 4.0 mg ℓ^{-1} except for two sampling dates in January and two in August. The high nitrate concentrations at the inlet of Felkner Ditch were probably due in part to nitrification of ammonia coming out of the waste ponds; ammonia concentrations at Site 1 were very high (Appendix II; Fig. 4) and this ammonia was most likely oxidized to nitrate as the water flowed downstream. Further addition of nitrate occurs from field runoff and as the stream flows through the marshland preceding the lake.

In Hammond Ditch, nitrate concentrations also increased as water proceeded downstream. At Site 3 (the outlet of Dewart Lake) the con-

centrations remained below 1.0 mg ℓ^{-1} for the entire study period. However, at Rink's farm (Site 5) and the inlet to the lake (Site 6), nitrate concentrations were higher. For the most part, the values were lower than those of Felkner Ditch. Apparently, nitrate was added to the stream water from field runoff as it moved toward the lake. This is especially evident in winter and early spring before the crops are planted.

Organic N

We had some technical problems with the analysis of organic nitrogen during the early portion of this study. We originally began analyzing organic nitrogen using the micro-Kjeldahl technique. However, we were unable to obtain satisfactory precision with this technique and after consultation with EPA officials in Cincinnati and university chemists, we switched to a persulfate digestion technique described by Raveh and Avnimelech (1979). This technique was perfected and began producing reliable results beginning in February.

Concentrations of organic nitrogen in the two inlets and the sole outlet of Lake Waubee showed similar trends throughout the study period (Appendix II; Fig. 7). In February and March, organic N concentrations were about 2-3 mg ℓ^{-1} in all three streams. In late March, the values climbed to 15 mg ℓ^{-1} in all three streams. In the remaining spring and summer months, the concentrations of organic N stayed below 5 mg ℓ^{-1} in the outlet. Values were a little higher at Sites 5 and 6 of Hammond Ditch, averaging above 5 mg ℓ^{-1} in late summer. The highest concentrations of organic nitrogen were found in Felkner Ditch where values remained above 5 mg ℓ^{-1} for the entire sampling period.

Silica

Silica concentrations in Lake Waubee vary from stream to stream. Concentrations in the outflow of the lake were very low, remaining less than 1.0 mg ℓ^{-1} for much of the study period. Concentrations in the two inlets to the lake, however, were much higher. The silica levels for all tributary sampling sites are shown in Figure 8 of Appendix II.

In Felkner Ditch there was not much difference in silica levels among the two sampling sites. Concentrations remained above 3.5 mg ℓ^{-1} for most of the time period except during high runoff in late February when they dropped to less than 0.6 mg ℓ^{-1}.

Silica concentrations in Hammond Ditch were much lower than Felkner Ditch and they showed some differences among sites. At the origin of the stream, Site 3, silica levels were low and remained so throughout the study period. The two sites downstream, however, had higher silica concentrations.

Residue

Total

The amount of total residue in the streams of Lake Waubee varied very little over the study period (Appendix II; Fig. 9). During most of the period, total residues remained below 0.5 g ℓ^{-1} at all sampling sites. However, in mid-February the values increased almost six fold to 3.0 g ℓ^{-1} during spring snow melt and associated runoff. Concentrations of total residues returned to low levels by late February. No significant differences in total residues among the sampling sites was noted.

Organic

Levels of organic residues in the tributaries of Lake Waubee remained constant throughout the study period (Appendix II; Fig. 10). Concentrations

of organic residues averaged about 0.10 to 0.25 g ℓ^{-1}. No significant differences were noted among sampling sites, except at Site 2 in early February when the organic residue concentration reached 1.5 g ℓ^{-1}. No explanation for this increase is apparent.

Organic residues accounted for about 50% of total residues at sampling sites for the major portion of the study period. However, during the high residue loads associated with spring snow melt, the amount of organic residues did not increase. This indicates that the heavy loading of residues to the stream during high runoff periods is mostly inorganic in nature.

Particulate Matter

Total

Total particulate matter in the two inlets and single outlet of Lake Waubee showed similar trends. Values in excess of 200 mg ℓ^{-1} were reported in December and January at all sampling sites. Levels dropped to less than 10 mg ℓ^{-1} for the remainder of the year (Appendix II; Fig. 11). Felkner Ditch had slightly higher values than either Hammond Ditch or the lake outlet.

Organic

Particulate organic matter concentrations paralleled the total particulate matter concentrations at all sampling sites (Appendix II; Fig. 12). In general, particulate organic matter comprised over 75% of the total particulate matter on all dates.

Total Alkalinity

The total alkalinity concentrations of the tributaries of Lake Waubee are shown in Figure 13 of Appendix II. There appears to be a net loss

of alkalinity to the lake. The outlet of the lake, Site 7, has lower total alkalinity, about 180 mg ℓ^{-1}, than the two inlets.

The highest total alkalinities are found in Felkner Ditch. At the duck plant waste ponds, alkalinities remained above 350 mg ℓ^{-1}. Total alkalinity values decrease downstream at Site 2 to less than 300 mg ℓ^{-1}, but these are still higher than any of the sites in Hammond ditch.

In Hammond Ditch, total alkalinity concentrations varied by almost 100 mg ℓ^{-1} from a high of 250 mg ℓ to a low of 100 mg ℓ^{-1}. The outlet of Dewart Lake, Site 3, had the lowest values in the stream.

V. LAKE MONITORING

A. Physical variables

Temperature

Temperature fluctuations in Lake Waubee show a pattern typical of northern latitude dimictic lakes (Appendix III; Figs. 1 a-d). In November, both sites exhibited isothermal conditions at 5.5° C. Under ice cover in January, surface temperatures dropped to 2.0° C at the deep station and 1.5° C at the shallow station, while deeper water was slightly warmer. This inverse thermal stratification was evident at both sites. By March, lake temperatures began rising as the lake began warming. Temperatures were slightly higher at the shallow station (5.0° C) than at the deep station (4.0° C). During April and May the lake continued to warm. By late May and early June, the lake had stratified with a thermocline beginning at 3.0 m. Bottom temperatures in the deep station remained around 10-12° C throughout the summer, while the surface temperatures climbed to 20-24° C. The shallow station also showed thermal stratification, but the bottom temperatures remained around 16-18° C.

Conductivity

Conductivity measurements in Lake Waubee show distinct differences between sampling dates as shown in Figures 2 a-e of Appendix III. Early deep station conductivity values were fairly constant with depth, averaging around 460 $\mu S\ cm^{-1}$. By mid-July, however, conductivity values showed sharp clinograde profiles. Conductivity was low at the surface and increased dramatically in the hypolimnion. This pattern was even more obvious at the shallow station where sharp clinograde profiles were obtained on almost all sampling dates.

Turbidity

Turbidity profiles of Lake Waubee show only minor differences between sampling sites, but large differences throughout the study period (Appendix III; Figs. 3 a-d). Turbidity values remained below 5 NTU from December through early June. By late June, turbidity values increased to above 5 NTU. This is most likely due to the large algal blooms occurring at this time. This is further illustrated by the sharply clinograde profiles in late summer where turbidity values exceeded 10 NTU at the bottom depths of the lake.

Secchi disk

The secchi disk depth in Lake Waubee varied by almost three meters throughout the nine month study period (Appendix III; Fig. 4). In late November, secchi disk was about 2.5 m. Under the ice in January and later in early March, secchi disk depth remained at 1.0 m at the shallow station and 1.6 at the deep station. In early May, secchi disk depth increased dramatically to 4.0 m at the deep station, due to the demise of the phytoplankton population at this time. As algal biomass increased throughout the late spring and summer, secchi disk depths decreased to less than 1.0 m.

Light attenuation

The total attenuation coefficients of the upper 6 m of Lake Waubee ranged from about 0.66 m^{-1} to 0.79 m^{-1} (Appendix III; Table 1). Values of n_w changed drastically between sampling dates. In November when chlorophyll a values were high, almost all the light attenuation was due to the algal pigments (i.e., $n_{w/n} = 0$). In May, June, and July when chlorophyll a values were low, a smaller proportion of the total light attenuation was due to phytoplankton ($n_{w/n}$ ratios of 0.70 and greater).

B. Chemical variables

pH

Values of pH in Lake Waubee showed little variation with depth throughout the season (Appendix III; Figs. 5 a-d). Values averaged around 8.0, except in January when values reached 11.0.

Dissolved oxygen

Dissolved oxygen readings for Lake Waubee show some striking trends (Appendix III; Figs. 6 a-d). Oxygen levels in November were uniform with depth at 12.5 mg ℓ^{-1} for both sampling stations; this represents an oxygen saturation of 100%. However, the mid-January oxygen curves for both the shallow and deep station showed a decline with depth. Values decreased from 13.0 mg ℓ^{-1} at the surface to 11 mg ℓ^{-1} at the shallow station and 8.1 mg ℓ^{-1} at the deep station. This indicates that considerable heterotrophic activity was occurring in the lake at this time.

After spring turnover, oxygen concentrations remained uniform at about 12.0 mg ℓ^{-1} (100% saturation). By late April, however, a sharp decline in oxygen concentrations was noted below 9.0 m. By mid-May, the bottom 2-3 m of the lake were completely anoxic. Oxygen concentrations in the lower waters continued to decline, and by late June no oxygen existed below 6.0 m. This situation continued throughout the summer. Oxygen concentrations of the epilimnion during this time remained close to, or slightly above, 100% saturation.

Phosphorus

Total

Total phosphorus concentrations in Lake Waubee varied throughout the study period (Appendix III; Figs. 7 a-d). From November to late May, average lake concentrations of total phosphorus dropped from 40 ug ℓ^{-1}

to about 20 µg ℓ^{-1}. Epilimnetic concentrations remained about 20 µg ℓ^{-1} throughout the spring and summer months. However, beginning in early June hypolimnetic concentrations of total phosphorus rose consistently until they reached values in excess of 80 µg ℓ^{-1}. This indicates that phosphorus was being released from the sediments as the hypolimnion remained anoxic.

Soluble Reactive

The amount of soluble reactive ("ortho") phosphorus in Lake Waubee remained very small throughout the study months (Appendix III; Figs. 8 a-e). Only under the ice in January did concentrations exceed 5.0 µg ℓ^{-1} in the water column. On all other sampling dates, the concentrations of soluble reactive phosphorus were almost undetectable. Beginning in May, however, the concentrations of soluble reactive phosphorus at depths of 12 m or greater increased consistently and reached values in excess of 70 µg ℓ^{-1}. This represents over 90% of the total phosphorus at those depths and is another strong indication that phosphorus was released from the sediments as the lower water layers went anoxic.

Nitrogen

Ammonia

Concentrations of ammonia in the water column of Lake Waubee varied seasonally (Appendix III; Figs. 9 a-e). From November through March, ammonia concentrations were uniform with depth, averaging 80-100 µg ℓ^{-1}. Beginning in May and continuing throughout the summer, clinograde ammonia profiles were found. Upper waters (0-6 m) had concentrations from 10-25 µg ℓ^{-1}. Below 6.0 m, ammonia concentrations increased with depth to maxima of several hundred µg ℓ^{-1}. This is another reflection of the anoxic conditions existing in Lake Waubee at depths greater than 6.0 m.

Nitrite

The nitrite concentrations in Lake Waubee showed some moderate seasonal patterns (Appendix III; Figs. 10 a-d). From November through April, water column concentrations were uniform with depth and ranged from 5-25 μg ℓ^{-1}. From May through August, epilimnetic concentrations ranged from 25-50 μg ℓ^{-1}. Sharp decreases of nitrite with depth were noted during these months as the hypolimnion went anoxic.

Nitrate

The nitrate concentrations of Lake Waubee followed classical seasonal trends (Appendix III; Figs. 11 a-e). From November through mid-May, nitrate concentrations were uniform with depth, ranging from 0.5 - 1.0 mg ℓ^{-1}. As the hypolimnion went anoxic from May through August, nitrate gradually disappeared from the lower depths of the lake. Epilimnetic concentrations remained close to 1.0 mg ℓ^{-1} during this time. In August, nitrate concentrations of the epilimnion decreased sharply to less than 0.1 mg ℓ^{-1}.

Organic

The organic nitrogen concentrations of Lake Waubee were the largest nitrogen fraction in the lake, comprising over 50% of the total nitrogen on all sampling dates. Concentrations of organic nitrogen varied little with depth or season (Appendix III; Figs. 12 a-e). Concentrations remained stable at about 3-4 mg ℓ^{-1} from April through August and showed only minor fluctuations with depth. The values of organic nitrogen obtained before April are dubious due to the technical problems encountered in the analysis.

Silica

Silica profiles in Lake Waubee follow classical seasonal trends (Appendix III; Figs. 13 a-d). Concentrations were very low in November due to the fall diatom bloom occurring at that time. Concentrations rose to 1.0 mg ℓ^{-1} by late March as the diatom flora decreased during winter. As the lake warmed in April and diatoms again grew, silica concentrations fell to less than 0.20 mg ℓ^{-1}. Beginning in mid-May and continuing throughout the summer, the diatom population was replaced and concentrations of silica again rose to values as high as 2.0 mg ℓ^{-1}.

Residue

Total

Total residue profiles in Lake Waubee show little differences throughout the sampling months (Appendix III; Figs. 14 a-e). All values remained around 0.3 g ℓ^{-1}. No obvious depth trends were noted.

Organic

Organic residue profiles in Lake Waubee also showed little seasonal differences (Appendix III; Figs. 15 a-e). Values averaged less than 0.1 g ℓ^{-1} the entire sampling period.

Particulate Matter

Total

The amount of total particulate matter in Lake Waubee remained only a small fraction (1-5%) of the total residue in the lake throughout the entire sampling period (Appendix III; Figs. 16 a-e). No obvious seasonal patterns were noted from November through June and values averaged from 2-6 mg ℓ^{-1}. In July and August, the upper layer of the lake had concentrations in excess of 10 mg ℓ^{-1} indicating the abundance of large algae at that time.

Organic

Profiles of particulate organic matter in Lake Waubee were similar to the total particulate matter profiles (Appendix III; Fig. 17 a-e). In general, particulate organic matter represented about 50% of the total particulate matter on any date.

Alkalinity

The total alkalinity values of Lake Waubee show drastic seasonal changes that reflect the changes in the algal biomass of the lake (Appendix III; Figs. 18 a-e). From November through May, alkalinity profiles remain constant at about 175-180 mg ℓ^{-1}. Beginning in June, the alkalinity of the epilimnion decreases to values as low as 125 mg ℓ^{-1} and sharp clinograde profiles are seen. This is most likely due to the large blue-green algal populations found during this time period.

C. Biological Variables

Bacteria

Results of the bacterial analyses of Lake Waubee and its tributary waters show that the lake receives fecal contamination, but that this contamination does not impair the water quality of the lake. Evidence also indicates that the fecal contamination is from animal, not human, sources.

Total coliform counts in Lake Waubee show that the in-lake waters have insignificant health hazards. Counts remained below 100 per 100 ml from April through August. The same is generally true with outflow water as well. Counts on the inlet ditches, however, were much higher, ranging up to 2400 per ml.

Hammond Ditch shows no consistent pattern of increasing or decreasing counts as one approaches the lake indicating variable sources of pollution

along its banks. Felkner Ditch shows a consistent increase in counts each month with inflow water being higher than those found at the road crossing near the Duck Pond. The total coliform counts are summarized in Table 2 of Appendix III.

Fecal coliform counts for Lake Waubee were low for in-lake samples and the outflow on all sampling dates. Fecal coliform counts on Felkner and Hammond Ditches, however, often exceeded the safety limit of 200 per 100 ml. No trend of increasing or decreasing counts may be seen in Hammond Ditch on a given sampling date, but increasing counts are evident in Felkner Ditch with highest counts routinely taken at the inflow to the lake. This supports the total coliform data seen previously. Fecal coliform counts are summarized in Table 3 of Appendix III.

Counts of fecal streptococci bacteria indicate a general increase during the warmer months (Appendix III; Table 4). The ratio of fecal coliform to fecal streptococci (FC:FS ratio) was used to determine the source (i.e. animal or human) of the fecal pollution. Values approaching 3.0 represent human waste contamination while values less than 0.7 are indicative of livestock wastes. On all dates except one, values of the FC:FS ratio for Lake Waubee remained less than 0.7 (Appendix III; Table 5). This strongly indicates that no human waste contamination is present in the lake or its watershed.

Standard plate counts for Lake Waubee show increasing values as the waters warmed (Appendix III; Table 6). In-lake counts were generally lower than tributary streams. Many in-lake samples showed a predominance of pigmented forms presumably flavobacteria, chromobacteria, and pseudomonads. Tributary samples showed few pigmented forms although counts were usually significantly higher on any given sampling date.

A survey around the lake taken on July 27, 1981, showed no large differences in bacterial counts among sites (Fig. 6). In-lake samples all show total and fecal coliform counts of 100 or less per 100 ml. These values are significantly lower than the counts obtained in the tributaries on this date. The results indicate that no area of the lake shoreline receives significant fecal pollution.

In summary, microbiological data indicate excessive fecal pollution in the two inlets to Lake Waubee throughout much of the summer. This contamination is due to animal wastes and appears in both Hammond and Felkner Ditches.. Shoreline as well as in-lake samples show no health hazards.

Chlorophyll a

Chlorophyll a values in Lake Waubee showed significant seasonal trends (Appendix III; Figs. 19 a-e). In November, 1980, chlorophyll a values averaged 50 $\mu g\ \ell^{-1}$ with a peak of 75 $\mu g\ \ell^{-1}$ at 10.5 m. This is a reflection of the large fall diatom population (see Phytoplankton section below). In January, chlorophyll a values had decreased to about 5 $\mu g\ \ell^{-1}$ except for immediately under the ice where light levels were high enough to permit phytoplankton growth. By March, 1981, and ice-free conditions, the chlorophyll levels were up to 15-20 $\mu g\ \ell^{-1}$ as the phytoplankton began responding to increasing water temperatures and light intensities. Concentrations of chlorophyll a increased to 30 $\mu g\ \ell^{-1}$ in early April and then decreased to about 10 $\mu g\ \ell^{-1}$ by early May as the spring diatom bloom waxed and waned. Chlorophyll a concentrations remained below 15 $\mu g\ \ell^{-1}$ throughout May, June, July and August. Values for the shallow station were nearly identical to those of the deeper station on all dates.

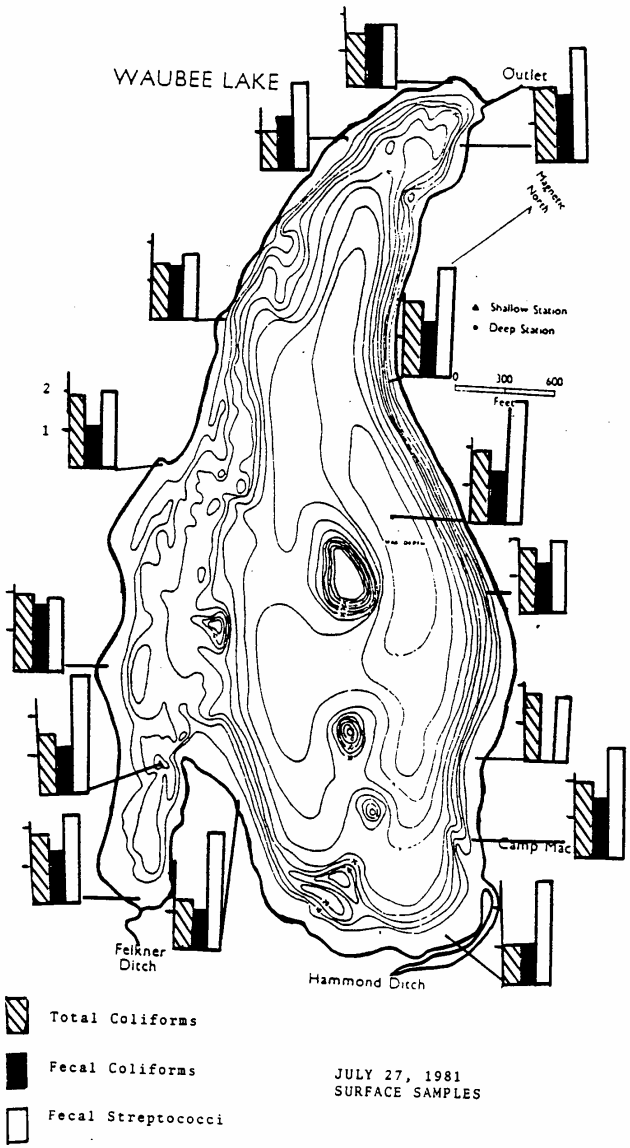
Phytoplankton Communities

Lake Waubee exhibited a well-defined pattern of seasonal phytoplankton succession. Following the fall overturn, the phytoplankton community was dominated by diatoms. During the early winter months, blue-green and green algae dominated the phytoplankton community. In late winter, diatoms, cryptomonads, blue-greens, and chrysophytes were the dominant species. During spring overturn, the phytoplankton community once again exhibited a diatom pulse. Cryptomonad, dinoflagellate, and blue-green algal species became dominant in early summer. Throughout the summer months, blue-green algal species dominated the phytoplankton community.

In late November, 1980, the diatom pulse in Lake Waubee consisted of Stephanodiscus niagarae and Fragilaria crotonensis (Appendix III; Fig. 20a). These species comprised over 95% of the phytoplankton volume and over 50% by number. Algal biomass, as estimated from cell volumes, was at its annual maximum, averaging ca. 3.8×10^7 μm^3 ml^{-1} and ca. 900 cells ml^{-1}. Chlorophyll a concentrations were correspondingly high at this time, averaging 45.1 μg ℓ^{-1}. No discernible differences could be detected between the communities of the deep and shallow stations.

In January, the phytoplankton community was dominated by the chlorophyte, Ankistrodesmus falcatus and the cyanophyte, Oscillatoria sp. (Appendix III; Fig. 20b). Diatom biomass increased with depth as a function of settling out under ice cover. Ankistrodesmus comprised over 60% of the total number of cells at all deep station depths. Oscillatoria comprised the greatest percentage by volume in the upper depths, but decreased as diatom biomass increased with depth. Algal biomass was at its annual minimum due to low temperature and light. Average algal volumes

Fig. 6. Bacteriological survey of Lake Waubee on 27 July, 1981. Histograms represent log numbers of bacteria.


WAUBEE LAKE
Outlet
Magnetic North
Shallow Station
Deep Station
0 300 600
Feet
2
1
Camp Mac
Felkner Ditch
Hammond Ditch
Total Coliforms
Fecal Coliforms
Fecal Streptococci
JULY 27, 1981
SURFACE SAMPLES

and numbers were 1.6 x 10^5 μm^3 ml^{-1} and 150 cells ml^{-1}. Chlorophyll a concentrations were correspondingly low, averaging 3.8 μg ℓ^{-1} except for the surface sample of 30.8 μg ℓ^{-1} which corresponded with the Oscillatoria maximum. Algal volume and chlorophyll a values were greater at the shallow station due to the greater density of Oscillatoria.

In late March, the diatoms Asterionella formosa, Stephanodiscus niagarae, and Fragilaria crotonensis; the cryanophytes Oscillatoria spp., Merismopedia spp.; the chrysophyte Dinobryon sociale; and Cryptomonas spp., comprised the dominant algal species (Appendix III; Fig. 20c). The small blue-green, Merismopedia sp., accounted for ca. 60% of the total number of cells, while diatoms comprised ca. 85% of the total volume. Average algal cell numbers ml^{-1} were ca. 600 ml^{-1} and average cell volume was ca. 5.5 x 10^5 μm^3 ml^{-1}.

During spring overturn in late March - early April, the algal biomass in Lake Waubee increased in response to increases in temperature, light, and nutrient concentrations. The resulting diatom pulse was less dramatic than the fall pulse, but still produced an average volume of ca. 4 x 10^6 $\mu m^3 ml^{-1}$ and average number of ca. 400 cells ml^{-1}. The dominant species of diatoms were Stephanodiscus niagarae, Asterionella formosa, and Fragilaria crotonensis (Appendix III; Fig. 20d).

Later in April, as silica became limiting, the larger diatoms were replaced by smaller species, such as Stephanodiscus tenuis. Cold-tolerant flagellates, such as Cryptomonas spp. and Dinobryon sociale also increased in number during this transition period (Appendix III; Fig. 20e). Although algal biomass and numbers increased during this period, average chlorophyll a concentrations decreased to ca. 13 μg ℓ^{-1} due to the smaller ratio of chlorophyll to unit volume in these smaller algal species.

In early May, as water temperature increased, the blue-greens, Oscillatoria and Chroococcus became dominant in the epilimnion. A small colonial green algae, Elakatothrix viridis, comprised ca. 25% of the total number, but did not significantly contribute to the total volume (Appendix III; Fig. 20f). As the diatoms from the spring pulse died and settled to the bottom, average numbers/ml decreased to ca. 366 cells ml^{-1}, and chlorophyll a concentration decreased to ca. 7 $\mu g\ \ell^{-1}$.

In late May, the phytoplankton community underwent another transition (Appendix III; Fig. 20g). Biomass of Oscillatoria and Chroococcus remained about the same as in early May, but the diatoms, Stephanodiscus niagarae, Stephanodiscus tenuis, Fragilaria crotonenis, and Asterionella formosa seemed to undergo a secondary bloom, comprising once again ca. 65% of the volume. Cryptomonas spp. were the dominant species by number, comprising ca. 60%. Dinobryon sociale also occurred in greater numbers at this time. Accordingly, average chlorophyll a concentration was ca. 8.0 $\mu g\ \ell^{-1}$. Again no significant differences were noted between the deep and shallow stations.

In early June, the community again changed as Microcystis flos-aqua and Chroococcus became dominant, comprising ca. 70% by number. However, the dinoflagellate, Ceratium hirundinella, appeared in the epi- and metalimnions to comprise ca. 60% of the total algal volume (Appendix III; Fig. 20h). Also Dinobryon sociale increased with depth, while cryptomonads declined, possibly due to zooplankton grazing pressure. Biomass calculations may be underestimated for this date, however, due to the high concentrations of nanoplankton.

In late June, the blue-greens, Chroococcus spp., Gomphosphaeria sp. and Microcystis flos-aqua comprised the dominant species by number, com-

prising ca. 60% (Appendix III; Fig. 20i). However, Ceratium hirundinella still persisted as the dominant alga based on biomass, comprising ca. 70% of the total volume.

In July, in response to warmer temperatures and nutrient concentrations (high N, low P), cyanophytes became solely dominant. Chroococcus spp., Microcystis spp., Gomphosphaeria, and Oscillatoria spp. comprised over 90% of both the total volumes and numbers. Epilimnetic populations ranged from 2000-4 000 ml^{-1} while hypolimnetic numbers decreased to 300-400 ml^{-1} in response to low light, low D.O., and high H_2S concentrations (Appendix III; Fig. 20 j-k).

Cyanophytes remained dominant throughout August. Oscillatoria spp. Gomphosphaeria sp., Merismopedia sp., Chroococcus sp., and Microcystis spp. were the prevalent species and comprised over 95% of both numbers and volumes.

The change in algal biomass during the study period is shown in Figures 21a and b of Appendix III. The average number of cells ml^{-1} ranged from a low of only 100 or so per ml in late January to a high of over 4 000 per ml in mid-July. Changes in algal volume showed similar trends. No obvious differences were noted with depth or between the deep and shallow stations.

Primary productivity

Integral photosynthesis in Lake Waubee totaled 308.91 mg C m^{-2} h^{-1} on June 11. Primary productivity was greatest at the surface (100 mg C m^{-2} h^{-1}), and declined with depth. Gross photosynthesis ceased at approximately 9.0 m, coinciding with the 1% surface light level. No surface inhibition was apparent.

On July 30, integral photosynthesis totalled only 194.7 mg C m^{-2} h^{-1}. Gross photosynthesis was limited at the surface due to photoinhibition. The maximum of 70 mg C m^{-2} h^{-1} was obtained at 2 m. Gross photosynthesis ceased at 5.0 m, about 1.5 m above the 1% light level. Primary productivity profiles for both dates are presented in Figure 22 of Appendix III.

Algal assay for nutrient limitation

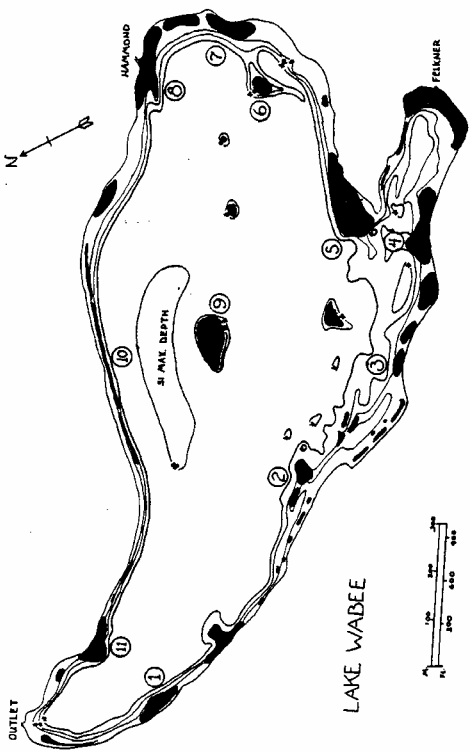
Results of the E.P.A. A.A./B.T. (Algal Assay/Bottle Test) clearly indicate that phytoplankton growth in Lake Waubee during the summer months is phosphorus-limited (Appendix III; Fig. 23). Addition of 0.05 mg P l^{-1}, singly and in combination with 1.00 mg N l^{-1}, stimulated a maximum standing crop of almost three times that of the lake water control. Addition of nitrogen and EDTA did not result in an increased yield relative to the control. The differential response to N and P additions is reflected by the ambient surface nutrient concentrations in the test lake water. The ratio of inorganic N to soluble reactive P in the test lake water was ca. 250:1, indicating an extremely phosphorus limited condition. The total N to total P ratio of 189:1 also indicated extreme phosphorus limitation.

Vascular plants

The macrophyte beds in Lake Waubee cover 6.4% of the lake surface (Fig. 7). The greatest densities occurred at sampling sites 4, 5, and 6. The average water depth of the sampling sites was 2.0 - 2.5 m.

Changes in the total lake biomass of aquatic macrophytes throughout the May - August sampling period are shown in Figure 24 of Appendix III. Initial biomass in May totalled 6.58 x 10^4 kg dry weight. Biomass peaked in mid-June at 9.1 x 10^4 kg dry weight and then declined consistently

Fig. 7. Distribution of macrophytes in Lake Waubee.


N
HAMMOND
FELKNER
OUTLET
31 MAX. DEPTH
1
2
3
4
5
6
7
8
9
10
11
LAKE WABEE

through August. The ratio of dry weight to wet weight of the macrophytes ranged from 0.09 to 0.13 throughout the season. Areal biomass values ranged from 20 to 340 g dry weight m^{-2} during the sampling period.

There are several macrophyte species found in Lake Waubee. The dominant plant in most areas of the lake is Myriophyllum spicatum, the Eurasian mil-foil. Other species such as Potamogetan pectinatus, P. crispus, P. illinoensis, Chara spp., Ceratophyllum demersum, and Vallisneria americana were found in specialized locations of the lake. Many of these species exhibited maximum growth and biomass in late summer as their competitor, M. spicatum, declined. It is interesting to note that the species found in Lake Waubee in 1981 are similar to those found in 1947 survey by Wohlschlag (Appendix III; Table 7). However, the relative abundances of the species appears to have changed considerably.

The nitrogen and phosphorus content of the macrophyte tissue was examined in detail. The amount of phosphorus in the macrophyte tissue remained in the range of 0.8 - 1.4 mg P (g dry weight)$^{-1}$ throughout the season. This concentration is near the critical P concentration of 0.079% provided by Gerloff and Krumbholz (1966) suggesting that many of the aquatic macrophytes may be near phosphorus limitation at times throughout the growing season. The critical P concentration of M. spicatum, however, does not fall below its minimum value of 0.08%; this may be why M. spicatum is competitively dominant in Lake Waubee. Nitrogen content was higher ranging from 11 - 19 mg N (g dry weight)$^{-1}$.

The total amount of phosphorus tied up in macrophyte tissue ranged from 3 - 11 kg, while the total amount of nitrogen in macrophyte biomass ranged from 15 - 150 kg. Maximum nutrient pools were found in June, and decreased as macrophyte biomass decreased (Appendix III; Fig. 25).

Zooplankton

During the period of spring overturn, and concurrent with spring algal pulses, the zooplankton community experienced large population increases. The dominant spring rotifer was Keratella cochlearis. In late May, as the lake thermally stratified, K. cochlearis populations declined and Kellicottia longispina became the dominant rotifer species. The population of K. longispina persisted until late June, when Conochilus sp. became most abundant.

Daphnia galeata mendotae was the dominant cladocern species from spring until mid-summer. A sharp decline in this species was followed by increases in Diaphanosoma birgei and Chydorus sphaericus populations.

Two species of cyclopoid copepods dominated during the study period. The winter species was Diacyclops thomasi, which maintained dominance from fall overturn through mid-spring. During the onset of thermal stratification, Mesocyclops edax replaced D. thomasi as the major cyclopoid taxa, and it remained dominant until the beginning of September.

Skistodiaptomus oregonensis was the most abundant calanoid copepod species throughout the entire study period. Calanoids were generally less numerous than cyclopoids during virtually all sampling dates. Fluctuating population sizes of S. oregonensis during the summer months may in part be due to predation by fish and macroinvertebrate predators. Table 8 of Appendix III lists the major zooplankton species found in Lake Waubee during the study period.

VI. SEDIMENT ANALYSIS

Superficial sediment and interstitial water samples were collected in July using SCUBA techniques at 18 sites in Lake Waubee (Fig. 5).

Three basic sediment types were identified on the basis of textural qualities: sandy silt, fine organic silt, and small gravel-sand. Fine organic silt (Type 2) was the most abundant sediment type in the lake basin. Dry weight, moisture and organic content of each sediment type are given in Table 9 of Appendix III.

Phosphorus concentrations in the interstitial water of Lake Waubee were positively correlated with increasing depth and reached a maximum of 3159.7 µg P ℓ^{-1} at 15.5 m (station X). This trend was not evident in the first three samples taken from Transect B progressing lakeward from the Felkner inflow. The concentration of phosphorus in these samples (Q, P, and D) was high, and appeared to be inversely correlated with distance from the mouth of Felkner Ditch regardless of depth. Station Q, directly adjacent to the inflow at a depth of 0.75 m, had the highest concentration of interstitial phosphorus (2448.6 µg P ℓ^{-1}) along Transect B. Table 10 of Appendix III presents the phosphorus concentration of interstitial water at each station in Lake Waubee.

Acid-nonlabile, sediment-bound phosphorus concentrations exhibited a strong positive correlation with sample depth. Linear regression analysis of phosphorus content (y) against depth (x) revealed that depth explained over 90% of the variability in the data points ($r^2 = 0.903$). This analysis included all samples except Q, P and D. These samples were collected in close proximity to the Felkner Ditch inflow and had high phosphorus concentrations of up to 1684.3 µg P (g dry weight)$^{-1}$ of sediment (sample Q). Aside from these three samples, phosphorus content ranged

from 17.8 to 1160.3 µg P (g dry weight)$^{-1}$ of sediment. Table 11 of Appendix III provides complete data on acid-nonlabile, sediment-bound phosphorus content at each station.

Calculation of the lake sediment phosphorus pool required expression of total phosphorus content per unit volume of sediment. One square meter of sediment surface by 10 cm deep was the unit selected since studies have shown the top 10 cm to be the actively mixed sediment zone (Naumann 1930; Hayes 1964; Lee 1970). Phosphorus trapped in lower layers is essentially "locked-up" and made unavaliable to the overlying water. Hence, we have designated the term "unit sediment" to refer to a volume of sediment one m^2 by 10 cm deep.

The volume of water and mass (dry weight) of sediment included in the 100 cm x 100 cm x 10 cm sediment unit was calculated for each of the three sediment types by multiplying the values listed in Table 9 of Appendix III by 10^5. Sandy silt (Type 1) contained 74.27 ℓ of water and 43.63 kg dry weight per sediment unit. Fine organic silt, Type 2, contained 90.60 ℓ of water and 14.31 kg dry weight per sediment unit. Small gravel-sand (Type 3) contained 46.23 ℓ of water and 126.04 kg dry weight per sediment unit.

The amount of phosphorus tied up in the interstitial water per sediment unit was calculated by:

$$S_I = \frac{B \times C}{1000} \qquad 1)$$

where

S_I = total phosphorus content {mg P $(10^5$ cm$^3)^{-1}$}

B = phosphorus concentration in interstitial water (µg ℓ$^{-1}$)

C = total water content {ℓ $(10^5$ cm$^3)^{-1}$}

Acid-nonlabile sediment-bound phosphorus was calculated in a similar fashion:

$$S_B = D \times E \qquad 2)$$

where

S_B = sediment-bound total phosphorus {mg P $(10^5\ cm^3)^{-1}$}

D = phosphorus content of sediment {mg P (kg DW of sediment)$^{-1}$}

E = total dry weight content (kg DW sediment)

Determination of the total phosphorus pool in the sediments of Lake Waubee was accomplished by calculating the amount of phosphorus in each five foot depth interval and summing these values. The total phosphorus content per unit sediment, S_t {g P $(10^5\ cm^3)^{-1}$}, in each five foot interval was calculated as follows: 1) multiple data points in any five foot interval were averaged to determine the mean, or 2) values for unsampled strata were estimated by averaging the values of S_t calculated for the intervals immediately preceding and following the unknown stratum. The total phosphorus in each stratum as g P was determined by multiplying the value of S_t {g $(10^5\ cm^3)^{-1}$} by the number of sediment units ($10^5\ cm^3$) in that interval. Calculations of the number of sediment units in each stratum were difficult due to the irregular geometric configuration of the lake basin. Numerical analysis was employed to estimate the proportion of sediment area in each depth stratum. The surface area of saggital sections through the lake at each five foot depth interval was determined planimetrically from the bathymetric map (Appendix III, Table 12). Each isobath was then mathematically converted to a circle of equivalent area. The resultant series of circles was then oriented according to depth along a perpendicular axis running through their centers, forming a cone with a base equal to the surface area of the lake and a height equal to the

maximum depth. The cone was sectioned into frustra based on depth, and the surface area of each frustrum was approximated by using this equation:

$$2\pi \int_0^5 X \cdot \sqrt{1 + \left(\frac{dx}{dy}\right)^2} \cdot dy \qquad 3)$$

The sediment surface area of each depth interval was summed to yeild total surface area of the entire lake basin. Using the percentages obtained through numerical analysis, the total area of sediment surface in each depth stratum could then be calculated using:

$$A_x = \phi \cdot A_t \qquad 4)$$

where

A_x = basin surface area in each 5 ft. stratum (m^2)

ϕ = relative % of A_t in stratum X

A_t = total lake basin area (9.102×10^5 m^2)

The total amount of phosphorus contained in the sediments of a given depth interval was thus calculated as:

$$P_x = \frac{A_x \cdot S_t}{1000} \qquad 5)$$

where

P_x = sediment phosphorus pool in interval X (g)

A_x = sediment units in interval X (m^2)

S_t = unit P content for interval X {mg P (unit sediment)$^{-1}$}

The total phosphorus pool for each depth stratum is given in Table 12 of Appendix III.

Data indicate that most of the phosphorus has accumulated in the deepest part of the basin. Sediments deeper than 35 ft. constitute about one-third of the total surface area of the basin, but contain approximately one-half of the total phosphorus pool. This situation results from sediment

focusing, and is typical of many glacial lakes in the area.

Results of the phosphorus budget (see Section VIII A) indicate that approximately 70% of the phosphorus entering the lake is retained in the system. Virtually all of this eventually reaches the sediments where it accumulates. The total phosphorus pool contained in the superficial sediments of Lake Waubee is 9,369 kg. This amount is 16 times the measured annual phosphorus input, and constitutes 93% of all of the phosphorus present in the entire lake system (Table 4). Clearly, sediments act as a net sink for phosphorus in the Lake Waubee system.

VII. HYDROLOGIC BUDGET

The hydrologic budget of Lake Waubee was calculated by direct measurements of water movement through the lake system over the nine month sampling period. The basic hydrologic model used was:

$$V = Q + P + R - O - E \pm G \qquad 1)$$

where

V = change in lake volume

Q = tributary inputs (Felkner and Hammond Ditches)

P = precipitation on the lake surface

R = direct runoff

O = outlet

E = evapotranspiration

G = groundwater

The change in lake volume, V, was assumed to be zero since no measurable change in lake height was noted on a yearly basis.

The instantaneous volume flow of each inlet and outlet stream was calculated using empirically determined discharge curves. These curves were determined by fitting an equation of the form

$$H = \frac{H_{max} F}{F + k} \qquad 2)$$

where

H = water level height (cm)

H_{max} = maximum water level height (cm)

F = discharge ($m^3 s^{-1}$)

k = half saturation constant for flow

to plots of measured stream flow ($m^3 s^{-1}$) versus water level height (cm).

Best fit parameters H_{max} and k were obtained using a simplex optimization procedure (Nelder and Mead 1965; Deming and Morgan 1973; Morgan and Deming 1974; and King et al. 1975). Figures 1-3 of Appendix IV show the discharge curves for the tributary streams of Lake Waubee.

Daily discharge values for each stream were calculated from daily water level heights by rearranging equation 2 as

$$F = \frac{H \cdot k}{H_{max} - H} \qquad 3)$$

and converting instantaneous flow, F ($m^3\ s^{-1}$), to daily discharge ($m^3\ d^{-1}$). These daily discharges were numerically integrated over time to yield total water flow for each stream.

Precipitation was measured by installing rain gauges at three locations aroung the lake. However, vast discrepancies in the data collected by local residents made this information useless. Alternatively, precipitation data were supplied by the National Weather Service station at Warsaw (Appendix IV; Table 1). Due to the close proximity of Lake Waubee to Warsaw and the uniformity of physiographic and climatic features in the region, this data was assumed to be representative of ambient precipitation conditions at the lake.

Evapotranspiration was estimated using the data of Reussow and Rohne (1975). Studies have shown that values for evapotranspiration do not deviate significantly from such published data.

No direct measures of groundwater flux or direct runoff were made. These two hydrologic categories were grouped together and solved by difference from equation 1.

Hydrologic data were collected for a nine month period from December, 1980, through August, 1981. Table 2 lists the measured values for this

time period. For determination of a yearly hydrologic budget, the nine month values were corrected to 12 month values using the ratio of

$$92.76 / 110.72 = 0.8378 \qquad 4)$$

which is the ratio of total rainfall during the study period (92.76 cm) to total rainfall during the 12 month period from September, 1980, through August, 1981 (110.72 cm). Thus, all reported values in the hydrologic budget are for the period commencing on 1 September, 1980, and ending 31 August, 1981.

The yearly hydrologic budget of Lake Waubee is summarized in Table 2. A total water input, Q, of 8.331×10^6 m^3 entered Lake Waubee during the 12 month period. Hammond Ditch was the major input, contributing 5.272×10^6 m^3 y^{-1} or 63.3% of the total. Felkner Ditch transported 2.219×10^6 m^3 y^{-1} or 26.6% of the yearly water. Direct lake precipitation of 8.397×10^5 m^3 y^{-1} accounted for the remaining 10%.

The outlet flowed continuously during the entire study period and transported 7.819×10^6 m^3 y^{-1} of water from the lake. This accounts for 93.8% of the water leaving the lake system. Evapotranspiration, estimated at 60.96 cm m^{-2} y^{-1}, represented a net loss of 4.624×10^5 m^3 y^{-1} or 5.6% of the total export. Since lake storage was relatively constant, groundwater flux and direct lakeshore runoff were solved by difference. This calculated net loss of 5.00×10^4 m^3 y^{-1} representes only 0.6% of the measured inflow. Thus, the measured input and output of water from Lake Waubee agree exceptionally well. Figure 8 showes the relative hydrologic contribution of each input and output source for Lake Waubee.

The hydraulic residence time of water in the lake, t_w, was calculated according to the formula

$$t_w = \frac{V}{Q} \qquad 5)$$

where

V = lake volume (m^3)

Q = mass water loading ($m^3\ y^{-1}$)

For Lake Waubee this becomes

$$t_w = \frac{6.017 \times 10^6\ m^3}{8.331 \times 10^6\ m^3\ y^{-1}} = 0.72\ y$$

Thus, it takes 0.72 y for the water volume of the lake to be replaced. This short residence time greatly affects the response of the lake to a given nutrient load.

Areal water loading, q_s ($m\ y^{-1}$), for Lake Waubee is given by

$$Q_s = Q/A_o \qquad 6)$$

where

Q = mass water loading ($m^3\ y^{-1}$)

A_o = surface area of the lake (m^2)

Hence,

$$q_s = \frac{8.331 \times 10^6\ m^3\ y^{-1}}{0.7585 \times 10^6\ m^2} = 10.98\ m\ y^{-1}$$

This areal water loading value is useful for modelling nutrient concentrations in the lake.

TABLE 2.

Lake Waubee hydrologic budget.

Source	Volume ($m^3\ y^{-1}$)*
Hammond Ditch	5.272×10^6
Felkner Ditch	2.219×10^6
Precipitation	8.397×10^5
Groundwater & Runoff**	-5.000×10^4
Evapotranspiration	-4.624×10^5
Outflow	-7.819×10^6

* Adjusted by the ratio of 9 month precipitation to 12 month precipitation (see text for details).

** Calculated by difference.

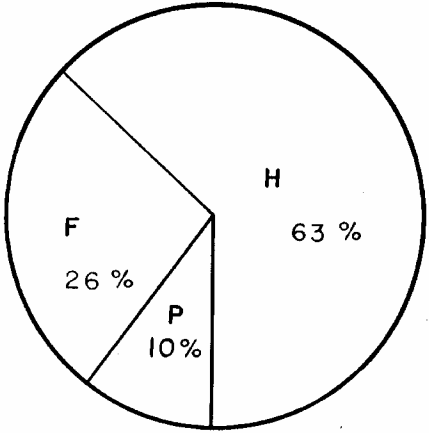
$$Q = 8.331 \times 10^6\ m^3\ y^{-1}$$

$$t_w = V/Q = \frac{6.017 \times 10^6}{8.331 \times 10^6} = 0.72\ y^{-1}$$

Fig. 8. Hydrologic budget for Lake Waubee. Symbols denote Felkner (F), Hammond (H), precipitation (P), Outflow (O) evapotranspiration (E), and groundwater (G).

HYDROLOGIC BUDGET

LAKE WAUBEE



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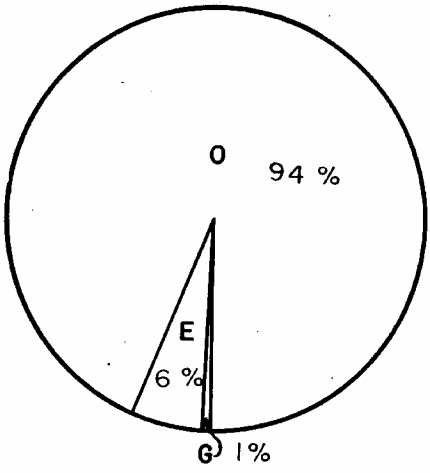

OUTPUT

VIII. NUTRIENT BUDGETS

A. Phosphorus

Construction of the phosphorus budget involved quantification of the phosphorus flux through the lake system using the equation:

$$M_p = Q + P + R + S + DF - O \pm Sd \pm G \qquad 1)$$

where

M_p = net loading of phosphorus (kg P y^{-1})

Q = streamflow input (kg P y^{-1})

P = precipitation input (kg P y^{-1})

R = direct runoff input (kg P y^{-1})

S = septic input (kg P y^{-1})

DF = dry fallout input (kg P y^{-1})

O = outflow (kg P y^{-1})

Sd = sediment (kg P y^{-1})

G = groundwater (kg P y^{-1})

Groundwater and direct runoff contributions were considered insignificant since they contributed less than 1% of the water loading to the lake. Sediment loading was found from Equation 1 by difference. All other values were measured or calculated directly.

Measurements of phosphorus loadings were made from December, 1980, through August, 1981. The monthly loadings of the two inlets and Outlet of Lake Waubee are presented in Table 3. These nine month totals were adjusted to yearly totals in the same manner as the hydrologic budget (i.e. using the ratio of rainfall in nine months to the total twelve month rainfall). Hence, the reported totals represent 12 month values and these are also shown in Table 3.

TABLE 3.

Monthly stream flow phosphorus flux through Lake Waubee.

Month	Felkner (kg P)	Hammond (kg P)	Outlet (kg P)
Dec.	9.63	4.30	17.03
Jan.	9.63	6.40	10.97
Feb.	22.72	25.31	8.56
March	23.16	5.95	15.13
April	24.08	19.08	20.66
May	28.00	24.02	22.07
June	55.09	52.44	40.70
July	7.37	16.60	5.66
Aug.	1.61	6.02	3.47
9 mo. total	178.9	160.1	144.3
Yearly value*	213.5	191.1	172.2

* Adjusted by the ratio of 9 month to 12 month precipitation. (See text for details).

Total phosphorus loading from the tributary streams, Q, was determined by multiplying average daily phosphorus concentration (mg P m^{-3}) by total daily water flow (m^3 d^{-1}). The resultant daily phosphorus loads (g P day^{-1}) were numerically integrated over time to yield annual phosphorus load.

The two inlets to Lake Waubee collectively supplied 69.3% of the yearly phosphorus loading of 583.8 kg. Felkner Ditch contributed 213.5 kg y^{-1} or 36.6% of the yearly total. Hammond Ditch transported 191.1 kg y^{-1} or 32.7% of the phosphorus entering the lake during the twelve month period. Remember that Hammond Ditch has a total streamflow volume over twice that of Felkner (see Table 2). This indicates that phosphorus concentrations in Felkner Ditch are much higher than those in Hammond.

Both inlet streams showed considerable temporal variation in loading which was positively correlated with streamflow volume. Maximum phosphorus input to the lakes from both streams occurred in June. In this month, Felkner Ditch transported 55.1 kg and Hammond Ditch transported 52.4 kg of phosphorus to the lake. This represents 25.8% and 27.4% of the yearly total for each of these streams, respectively (Table 3).

Phosphorus input from direct precipitation was estimated using a rainwater phosphorus concentration of 0.07 mg l^{-1} (Jorgensen, 1980). The total volume of precipitation falling upon the lake surface (8.397×10^5 m^3 y^{-1}) was multiplied by 0.07 g m^{-3} to yield a total phosphorus loading of 58.8 kg y^{-1}. This amounts to 10.1% of the mass phosphorus loading.

Input from dry fallout was calculated based on phosphorus loading coefficient of 0.08 g m^{-2} y^{-1} (Rast and Lee 1978). This value was

multiplied by the surface area of the lake (7.585×10^5 m^2) to give an estimated phosphorus loading of 60.7 kg y^{-1}. Approximately 10.4% of the total phosphorus entering the Lake Waubee system is contributed by this source.

Septic phosphorus loading was calculated according to the method of Reckhow and Simpson (1980) using the equation:

$$S = E_s \times C_t \times (1 - SR) \qquad 2)$$

where

S = total phosphorus input (kg y^{-1})

E_s = export coefficient for septic fields {kg(capita-y)$^{-1}$ y^{-1}}

C_t = total capita-years

SR = soil retention coefficient (unitless)

C_t is a weighted average of the total number of residents impacting the lake during the year. For Lake Waubee it was determined to be 398.1 (see Appendix V). An export coefficient for septic fields of 0.3 kg (capita-y)$^{-1}$ y^{-1} and a soil retention coefficient of 0.50 were selected for our estimate (Reckhow and Simpson 1980). Septic loading for Lake Waubee then becomes:

$$S = (0.3 \text{ kg capita-y}^{-1}\text{y}^{-1}) \cdot (398.1) \cdot (1-0.50) = 59.7 \text{ kg y}^{-1} \qquad 3)$$

A septic phosphorus loading of 59.7 kg y^{-1} represents 10.2% of the total phosphorus input. About as much phosphorus enters the lake from septic leakage as from precipitation or dry fallout.

Lake Waubee had a total phosphorus input from all sources of 583.8 kg y^{-1}. Hammond and Felkner Ditches each supplied about a third of the phosphorus loading. The remaining loading was evenly divided

among precipitation, dry fallout, and septic loading. Figure 9 shows the relative contributions of each source to the phosphorus loading of the lake.

The measured phosphorus loss via the outlet of Lake Waubee was only 172.2 kg y^{-1}. This indicates that 411.6 kg y^{-1} or approximately 70% of the phosphorus entering the lake is retained within the system. Calculations indicate that only minor amounts of phosphorus within the lake are channeled into plant and animal biomass. Table 4 shows that a full 93% of the phosphorus pool in the lake is tied up in the sediments. Hence, on a yearly basis the sediments serve as a net sink of phosphorus for Lake Waubee. A complete summary of the phosphorus budget of Lake Waubee is presented in Table 5.

Mass phosphorus loading is conveniently expressed on an areal basis. Areal phosphorus loading (L) is calculated as:

$$L = \frac{M}{A_o} \qquad 4)$$

where

L = areal phosphorus loading (g m^{-2} y^{-1})

M = mass loading of phosphorus (g y^{-1})

A_o = lake surface area (m^2)

For Lake Waubee this becomes

$$L = \frac{5.838 \times 10^5}{7.585 \times 10^5} = 0.770 \text{ g } m^{-2} \text{ } y^{-1} \qquad 5)$$

This value is very close to the low estimate of 0.7 g m^{-2} y^{-1} phosphorus loading predicted from the modelling techniques of Reckhow and Simpson (1980) using land-use categories for the watershed (see Appendix V.).

TABLE 4.

Compartmentalization of phosphorus within Lake Waubee.

Source	kg P *	%
fish	503	5.0
plankton	181	1.8
macrophytes	10	0.1
macrobenthos	10	0.1
sediments	9367	93.0

* See Appendix VI for details on the calculations of these values.

Fig. 9. Phosphorus inputs to Lake Waubee. Letters denote Felkner (F), Hammond (H), precipitation (P), dry fallout (DF), and septic (S).

PHOSPHORUS INPUTS

LAKE WAUBEE

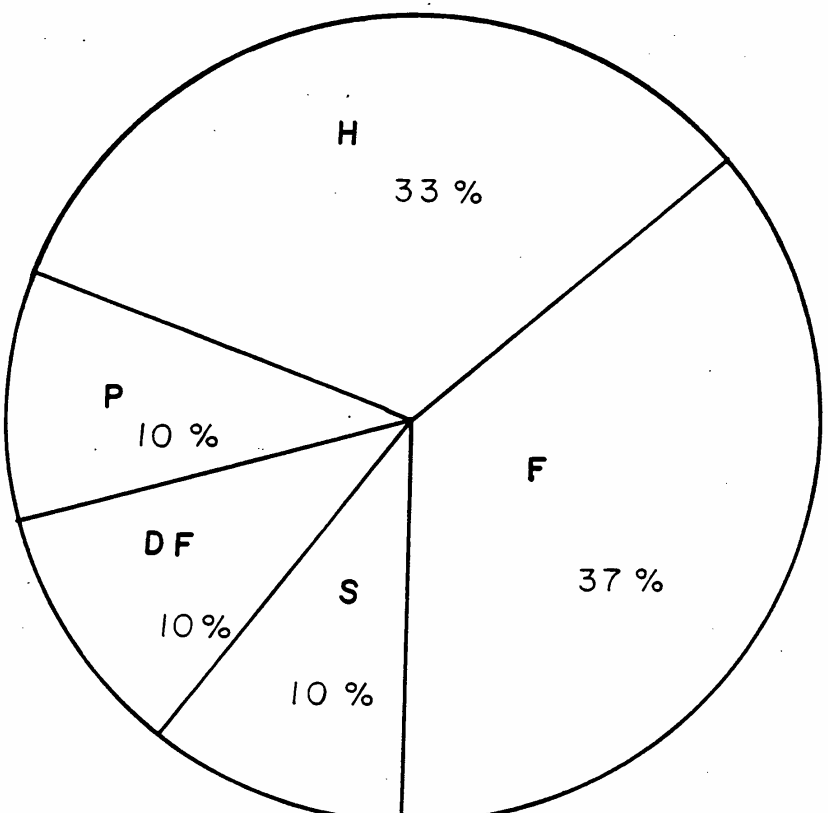

TABLE 5.

Lake Waubee phosphorus budget.

Source	Loading ($g\ y^{-1}$)*
Hammond	1.911×10^5
Felkner	2.135×10^5
Precipitation	5.877×10^4
Dry Fallout	6.068×10^4
Septic Loading	5.972×10^4
Outflow	-1.722×10^5

* Adjusted by the ratio of 9 month to 12 month precipitation. (See text for details.)

$$M_p = 5.838 \times 10^5\ g\ y^{-1}$$

B. Nitrogen

Construction of the nitrogen budget involved quantification of the nitrogen flux through the lake system using the equation:

$$M_n = Q + P + R + S + DF - O \pm Sd \pm G \qquad 6)$$

where

M_n = net loading of nitrogen (kg N y^{-1})

Q = streamflow N input (kg N y^{-1})

P = precipitation input (kg N y^{-1})

R = direct runoff input (kg N y^{-1})

S = septic input (kg N y^{-1})

O = outflow (kg N y^{-1})

Sd = sediment (kg N y^{-1})

G = groundwater (kg N y^{-1})

Groundwater and direct runoff contributions were considered insignificant since they contributed less than 1% of the water loading to the lake. Sediment loading was found from Equation 6 by difference. All other values were measured or calculated directly.

One important aspect of the above nitrogen budget needs to be mentioned. The input of nitrogen to the lake via nitrogen fixation and the loss of nitrogen from the lake via denitrification processes were assumed to be about equal thus cancelling each other in budgetary calculations. Hence, these terms do not appear in Equation 6. This assumption seems fairly valid because: 1) published nitrogen budgets show these two processes to be fairly equal and 2) the very high loadings of nitrogen from other sources means that both nitrogen fixation and denitrification probably compose only a small fraction of the nitrogen budget.

Inputs and outputs of total nitrogen were determined by summation of the loading of each nitrogen form:

$$TN = NH_3 + NO_2 + NO_3 + ON \quad 7)$$

where

TN = total nitrogen (kg y^{-1})

NH_3 = total ammonia (kg y^{-1})

NO_2 = total nitrite (kg y^{-1})

NO_3 = total nitrate (kg y^{-1})

ON = organic nitrogen (kg y^{-1})

Calculations of the nitrogen budget are based upon total nitrogen values. All future references to nitrogen refer to total nitrogen (TN).

Measurements of nitrogen loadings were made from December, 1980, through August, 1981. The monthly loadings of the two inlets and Outlet of Lake Waubee are presented in Table 6. These nine month totals were adjusted to yearly totals in the same manner as the hydrologic budget (i.e. using the ratio of rainfall in nine months to the total twelve months rainfall). Hence, the reported totals represent 12 month values and these are also shown in Table 6.

Total nitrogen loading from the tributary streams, Q, was determined by multiplying average daily nitrogen concentration (mg N m^{-3}) by total daily water flow (m^3 d^{-1}). The resultant daily total nitrogen loads (g N d^{-1}) were numerically integrated over time to yield annual nitrogen loading.

Hammond Ditch contributed 53,750 kg of nitrogen to the lake. This represents 66.6% of the total nitrogen loading to the system of 80,670 kg y^{-1}. The dominant nitrogen fraction in this input was nitrate, comprising 59.7% of the total. The remaining loading was mostly organic nitrogen (39.9%),

TABLE 6.

Monthly stream flow nitrogen flux through Lake Waubee.

Month	Felkner (kg N)	Hammond (kg N)	Outlet (kg N)
Dec.	2,247.	2,511	1,683
Jan.	762.	876	1,051
Feb.	1,676.	1,250	1,140
March	2,873.	2,474	2,769
April	3,530.	3,591	3,334
May	3,822.	3,981	5,706
June	4,219.	25,400	5,042
July	774.	3,053	921
Aug.	193.	1,897	729
9 mon. total	20,096	45,033	22,375
Yearly value*	23,986	53,751	26,707

* Adjusted by the ratio of 9 month to 12 month precipitation. (See text for details.)

with only trace amounts of ammonia and nitrite present. The ratio of N:P in Hammond Ditch inflow water was approximately 281:1.

Nitrogen input from Felkner Ditch totaled 23,990 kg y^{-1}. This amounts to 29.7% of the total nitrogen input to Lake Waubee. The inflowing water contained predominantly organic nitrogen (54.8%) and nitrate (44.6%). Ammonia and nitrite comprised less than 1.0% of the total nitrogen load. The N:P ratio in Felkner Ditch water was 112:1.

Streamflow inputs of total nitrogen accounted for 96.3% of the mass nitrogen loading to Lake Waubee (Fig. 10). Nitrogen loading appeared to be directly proportional to water flow. Hammond contributed 63.3% of the total water input and 66.6% of the nitrogen. Felkner, with a water loading of 26.6% of the total, supplied 29.7% of the total nitrogen load to the lake. This indicates that both sources have similar total nitrogen concentrations in their inflowing water.

Precipitation provided about 1% of the total nitrogen input. An estimated rainwater nitrogen concentration of 1.0 mg l^{-1} (Jorgensen 1980) was multiplied by lake surface precipitation volume (8.397 x 10^5 m^{-3} y^{-1}) to yield a total nitrogen loading of 839.8 kg y^{-1}.

Determination of nitrogen input from dry fallout was made using a nitrogen loading coefficient of 1.6 g m^{-2} y^{-1} (Rast and Lee 1978). A total estimated nitrogen input of 1,214 kg y^{-1} was derived by multiplying the loading coefficient by the lake surface area (7.585 x 10^5 m^2). Dry fallout represents 1.5% of the total nitrogen input.

Nitrogen export from septic fields was calculated by a modification of Reckhow and Simpson's (1980) equation in the form:

$$N = E_n \times C_t \times (1 - SR) \quad 8)$$

where

N = total nitrogen input (kg y^{-1})

E_n = nitrogen export coefficient for septic fields

{kg(capita-y)$^{-1}$ y^{-1}}

C_t = total capita-years

SR = soil retention coefficient (unitless)

Total capita-years (C_t), the weighted average number of residents impacting Lake Waubee during the year, was equal to 398.1 as determined previously. An export coefficient (E_n) of 2.2 kg(capita-y)$^{-1}$ y^{-1}. (Hook et al. 1978) and a soil retention coefficient of 0.0 were used. The equation for septic nitrogen loading thus becomes:

$$N = \{2.2 \text{ kg(capita-y)}^{-1} \text{ y}^{-1}\} \cdot (398.1) \cdot (1\text{-}0.0) = 875.8 \text{ kg y}^{-1} \quad 9)$$

Septic field contribution represents 1.1% of the total nitrogen input. Precipitation, dry fallout, and septic loading are all fairly equivalent sources of nitrogen. All three sources combined, however, comprise an insignificant (3.6%) fraction of the mass nitrogen loading to Lake Waubee.

The outlet transported 26,710 kg of nitrogen out of the lake. Organic nitrogen (69.3%) and nitrate (28.9%) were the major nitrogen fractions being lost. Organic nitrogen is exported in a much greater proportion than it is imported. Apparently, inorganic nitrogen forms are converted to organic compounds through biological activity as they pass through the lake system.

Mass nitrogen loading to Lake Waubee totaled 80,670 kg y^{-1}. Only 33% of this total is removed through the outflow. The remaining 67% (54,049 kg) is retained in the lake system. A complete summary of the nitrogen budget is presented in Table 7.

Fig. 10. Nitrogen inputs to Lake Waubee. Letters denote Felkner (F), Hammond (H), dry fallout (DF), septic (S), and precipitation (P).

NITROGEN INPUTS

LAKE WAUBEE

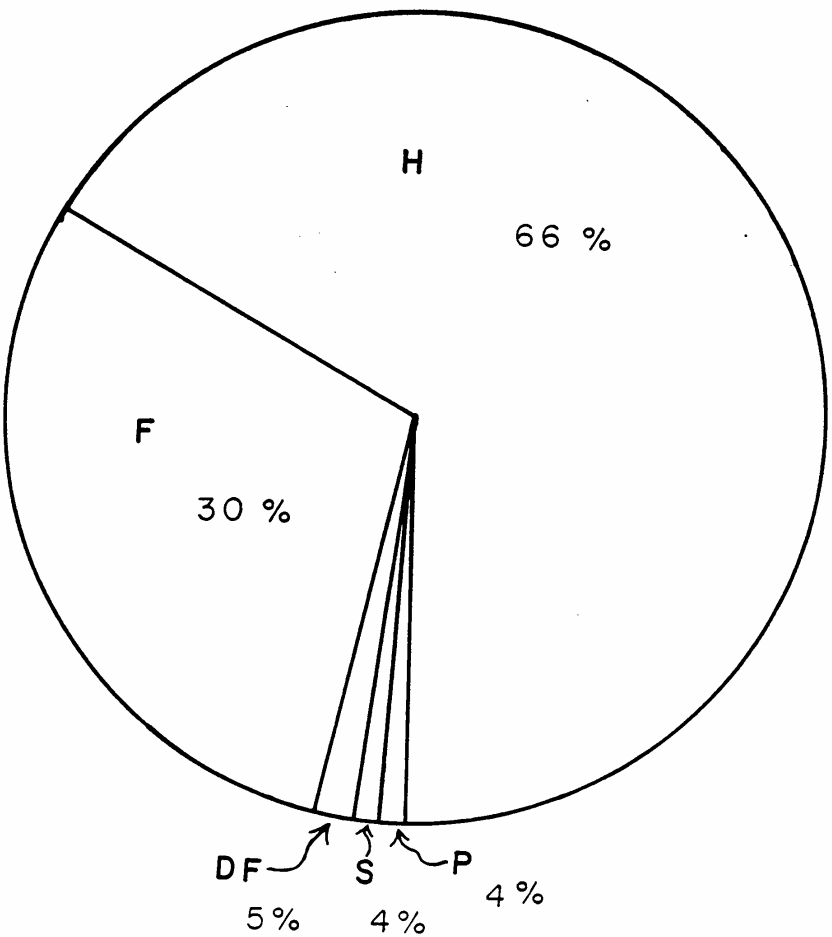

TABLE 7.

Lake Waubee nitrogen budget.

Source	Loading ($g\ y^{-1}$)*
Hammond	5.375×10^7
Felkner	2.399×10^7
Precipitation	8.398×10^5
Dry Fallout	1.214×10^6
Septic Loading	8.758×10^5
Outflow	-2.671×10^5

* Adjusted by the ratio of 9 month to 12 month precipitation. (See text for details.)

$$M_n = 8.067 \times 10^7\ g\ y^{-1}$$

Areal nitrogen loading is frequently calculated to facilitate data interpretation. The general equation is:

$$L_n = \frac{M_n}{A_o} \qquad 10)$$

where

L_n = areal nitrogen loading ($g\ m^{-2}\ y^{-1}$)

M_n = mass loading of nitrogen ($g\ y^{-1}$)

A_o = surface area of lake (m^2)

For Lake Waubee this becomes:

$$L_n = \frac{8.067 \times 10^7}{7.585 \times 10^5} = 106.4\ g\ m^{-2}\ y^{-1} \qquad 11)$$

This value can be divided by the areal phosphorus loading of 0.77 $g\ m^{-2}\ y^{-1}$ (see page 76) to yield an N:P loading ratio of 138:1. This tremendous nitrogen input leaves little doubt that Lake Waubee is phosphorus limited.

IX. MANAGEMENT AND RESTORATION STRATEGIES

The management of Lake Waubee involves both short term and long term strategies. Short term strategies are designed to provide quick resolution of a problem. However, they are cosmetic in nature, addressing the symptoms, not the cause, of the problem. Hence, they must be repeated on a regular basis. Long term strategies, on the other hand, address the cause of the problem and seek to remedy that cause so that problems do not reoccur. Long term strategies usually take more time to implement and may take years for the results to be seen.

The proposed management recommendations for Lake Waubee fall into both short term and long term strategies. Before we can consider specific strategies, however, we need to review the relative trophic condition of Lake Waubee to provide a background and framework for developing these management strategies.

Virtually all of the lakes in Indiana (n = 413) were classified according to trophic status and morphometry by Torke and Senft (1979). The trophic condition of each lake was estimated using Bonhomme's Trophic Index. Lakes were assigned eutrophy points based upon nutrient concentrations, dissolved oxygen levels, water transparency, and plankton community composition (Torke and Senft 1979). Possible scores ranged from a minimum of 0 to a maximum of 75. Lake Waubee was classified using data obtained during a 1975 survey by the Indiana State Board of Health, and was assigned a score of 60 which placed it into lake category IV D. This category consists of eutrophic lakes which have moderate to severe water quality problems.

Recalculation of eutrophy points for Lake Waubee based upon data from this study suggest a new score of about 20 eutrophy points. This places the lake into a new category, Group VI A, composed of lakes with moderately good water quality. In fact, based upon its new score, Lake Waubee is now in the top 20% of all the lakes in Indiana. We feel the broad discrepancy in the two scores may indicate a real change in the lake's trophic condition during the past several years. The data suggest that Lake Waubee may have been severely impacted from the 1960's to 1974 by the Maple Leaf Farms duck processing plant. In 1974, Maple Leaf Farms initiated a new method of waste handling which appears to have substantially reduced their direct nutrient loading to the lake. Therefore, it is possible that Lake Waubee is in a "recovery phase" following the abatement of this point source pollution. Observations of lake residents substantiate this suggestion, for they report a marked qualitative improvement in the water quality of the lake during the last three years. Further support for this idea comes from a comparison of the chlorophyll a and total phosphorus values for Lake Waubee with published criteria. According to Wetzel (1975), the value of both these parameters place Lake Waubee in the mesotrophic to meso-eutrophic categories. This again suggests that the water quality of Lake Waubee has improved.

In conclusion, our data suggest that Lake Waubee is currently a mesotrophic or only slightly eutrophic lake. It has above average water quality when compared to most other lakes in Indiana. Management strategies should, therefore, address the minor problems that do occur (i.e. short term solutions), but more importantly focus upon preserving

and improving the water quality of the lake to allow attainment of maximum recreational and aesthetic benefits.

Proposed Strategies

Results of this study show that Lake Waubee is phosphorus limited. This is indicated both by the nitrogen:phosphorus loading ratios as well as the in-lake N and P concentrations. Further evidence comes from the algal assay test which also showed that phosphorus was the limiting nutrient. Hence, long term management strategies should focus upon phosphorus control.

Implementation of short term strategies for Lake Waubee should focus upon controlling lake macrophytes ('weeds'). Although our data do not indicate a severe macrophyte problem, some residents would like to control weeds in selected areas. Control of algal biomass seems unnecessary since no severe problems were noted. Likewise, no short term nutrient control is needed since the water quality of the lake is relatively good.

After lengthy examination of all possible management alternatives, eight management strategies for Lake Waubee are proposed. These are presented in Table 8. Three of these are short term strategies and five are long term strategies. Detailed discussion of each strategy follows.

1. Weed Barriers

The morphometry of Lake Waubee and its associated plant community make it ideally suited to the use of vinyl-coated fiberglas mesh screening as a means of aquatic macrophyte (weed) control. Commercially, the product is known as 'Aquascreen'. It is a negatively bouyant, polyvinylchloride coated fiberglas mesh having 64 apertures per cm^2,

TABLE 8.

Proposed management strategies for Lake Waubee*

Strategy	Nature	Cost**	Effectiveness
1. Weed barrier	Short to intermediate term	$0.02/ft^2/year	100% macrophyte control
2. Chemical	Short term	$0.003/ft^2/year	75-100% macrophyte control
3. Harvesting	Short term	Minimal	50-75% macrophyte control
4. No till agriculture	Long term	Unknown	80-90% phosphorus removal on complying areas
5. Buffer zones	Long term	Unknown	25-75% phosphorus removal on complying areas
6. Wetland protection	Long term	$0	Up to 95% reduction in stream phosphorus concentration
7. Septic maintenance	Long term	Minimal	Maximum health protection
8. Development restriction	Long term	Unknown	Unknown

* See text for details of each strategy.
**Labor costs not included.

with each opening measuring approximately 1 mm^2. The material can be installed early in the spring by anchoring it to the bottom in direct contact with the sediments. It prevents macrophyte growth in two ways: 1) by reducing the available sunlight 50% to 60%, and 2) by forming a physical barrier to plant growth. Aquascreen can be installed later in the season directly over existing plants. Since it is heavier than water, it compresses the plants to the bottom where they die. The gases resulting from decomposition can harmlessly escape into the water through the mesh material. Special permits are not required to use this material.

Independent scientific investigations have shown fiberglas mesh screens to be an extremely successful and ecologically sound method of aquatic macrophyte control. Perkins (1980) states, "...the screens were highly effective for removing nuisance conditions associated with aquatic plant growth, maintaining a plant-free water column for the duration of placement, and significantly reducing regrowth after panel removal (Perkins, 1980; Boston, 1980)." Placement of the screens in early spring (April) resulted in a 78% to 100% reduction in plant biomass when compared to untreated control plots (Perkins, 1980). Mayer (1978) found that the screens completely eliminated rooted aquatic plants within a three-week time period, and limited regrowth of weeds to about 5% of normal plant cover. Aquascreen is effective in controlling numerous plant species including Myriophyllum spicatum (milfoil), Potamogeton crispus (curlyleaf pondweed), and Ceratophyllum demersum (coontail).

Aquascreen is commercially available in rolls 100 feet long by 7 feet wide. It is manufactured by the Menardi-Southern Corporation of

Augusta, Georgia. We have contacted a local distributor (Aquatic Control, Inc., P. O. Box 100, Seymour, Indiana 47274; 812/497-2410) and obtained the following price quotes:

Aquascreen Rolls (7' x 100')	
1 - 9 rolls	$140.00 each
10 or more rolls	$125.00 each

The minimum life expectancy of each roll is 10 years. Hence, macrophyte control could be accomplished for $0.02/ft^2/year ($140.00/roll x roll/700 ft^2 x 1/10 years). This is an extremely economical means of aquatic plant control.

It must be stressed that normal plant communities are essential components of lake ecosystems. Lake Waubee does not have a severe macrophyte problem, and we do not advocate widespread plant control. This makes the limited use of weed barriers especially inviting. One roll could be placed parallel to a dock and provide a weed-free channel to deeper water without harming the adjacent beneficial weed beds.

2. Herbicides

Herbicides have become popular as a means of aquatic macrophyte control. There are several types of herbicides that can be used. Most act to inhibit the photosynthetic process of the growing plants and are thus most effective during active growth of the young macrophytes. If applied properly, herbicides are extremely effective at controlling macrophyte growth.

Although herbicides are extremely effective at controlling aquatic plants, there are several factors which preclude us from recommending them unilaterally. They are expensive to use and provide cosmetic results which are only temporary. Plants killed by these chemicals quickly decompose and release their stored nutrients back into the water,

often stimulating further plant growth. When treatments are done on a large scale, the process of decomposition often leads to anoxic conditions which are harmful to fish and other organisms (Nichols and Keeney, 1976). Some herbicides are directly toxic to the fish and plankton communities of the lake (Kenaga and Moolenaar 1979), and in some instances the use of two or more herbicides in combination has resulted in a negative synergistic effect. In addition, the ramifications of long term treatment using many currently available herbicides is not fully documented. These chemicals must be used with caution to avoid ecological problems within the lake system.

The herbicide of choice for Lake Waubee would most likely be 2,4-D (2,4-D butoxyethanol ester) since this chemical has been used with success in the control of Myriophyllum spicatum in many lakes. When applied in a granular formulation (commercially available as Aqua-Kleen 20), 2, 4-D has proven effective in killing most of the roots and shoots of M. spicatum in treated areas (Goddard 1980). This chemical is advantageous in that it can be applied rapidly to large areas without inducing plant fragmentation. However, it cannot be applied in areas where the public may be exposed to the herbicide in detectable levels (Newroth 1980). The cost of this chemical is (prices from Aquatic Control, Inc.):

Aqua-Kleen 20 (50 lb. bag)	
1 - 19	$51.00
20 or more	$49.00

The suggested application rate is 100 - 200 lbs. per surface acre (1 - 2 lbs. per 430 ft^2). Using a medium value of 150 lbs. per acre

and an annual application rate, the cost of herbicide control with 2, 4-D becomes

$$\frac{\$49.00}{50 \text{ lb.}} \times \frac{150 \text{ lbs.}}{\text{acre}} \times \frac{1 \text{ acre}}{43560 \text{ ft}^2} = 0.003$$

or $\$0.003/ft^2/year$. This figure can be expected to increase as chemical costs rise.

Considering the relatively minor macrophyte problems in Lake Waubee, the negative potential side effects of chemical treatment, and the high degree of public usage of the lake, we do not recommend using this or any other herbicide under most normal conditions.

3. Harvesting

The Property Owners Association of Lake Waubee currently owns and operates a mechanical weed harvester. We strongly urge them to continue this practice as a component of the lake management scheme since the cost of such a procedure will be minimal. Our data on the plant community dynamics of Lake Waubee should enable the maximization of the effectiveness of this program.

Mechanical harvesting is advantageous because it allows immediate removal of the macrophyte biomass and the nutrients therein without the possible negative side effects of herbicides (Brooker and Edwards 1975). In addition, it is a site-specific control measure and does not present a hazard to non-target weed beds. There is also a "carry-over effect" that results from weed harvesting programs. Nichols and Cottam (1972) found reduced macrophyte biomass in the year following the implementation of a harvesting program, with the most significant long-term effects occurring in deeper weed beds (approximately 1.5 m

of water). They determined that three harvests the previous year reduced biomass most effectively in their study lake.

Although we endorse macrophyte harvesting as a short term management strategy in Lake Waubee, several potential negative attributes of the technique must be considered. First and most importantly, the dominant plant species in the lake is Myriophyllum spicatum (Eurasian milfoil). This species reproduces asexually by fragmentation during the growing season (Giesy and Tessier 1979). Therefore, the plant fragments generated by the harvesting process which are not collected will float to other suitable areas and continue growing into new mature plants. This is obviously counterproductive to the intent of the program. Another potential problem is the disposal of the plant material once it is removed from the lake. It should be removed from the lakeshore, preferably to a location where the nutrients in the tissue will not return to the lake upon decomposition. Steps should be taken to minimize these potential negative effects, therefore allowing plant harvesting to be an integral part of the management of Lake Waubee.

The overall goal of the harvesting program is to remove plant biomass from desired areas in a manner which maximizes each harvest (Gerloff and Krombholz 1966). This is accomplished most successfully by harvesting during the period of greatest macrophyte biomass and nutrient standing stock. Peak plant biomass and tissue nutrient pools occurred in early June in Lake Waubee. This timing would be expected to vary somewhat on a yearly basis, but probably not more than a few weeks under normal conditions. Hence, early June would be the optimum time to initiate a macrophyte harvest.

We emphasize that large-scale macrophyte removal is not desireable in Lake Waubee. Extensive harvesting in shallow littoral areas could contribute to the erosion of littoral sediments by wave action (Dunst et al. 1974 as reported by Carpenter and Gasith 1977). This sediment resuspension and movement would increase water turbidity and possibly initiate the release of nutrients from the sediments. In addition, extensive macrophyte removal could cause biological damage to the invertebrate and fish communities. The lake property owners should select strategic sites within the lake and concentrate their harvesting efforts in these locations.

4. No Till Agriculture

The watershed of Lake Waubee is predominantly agricultural land. This diffuse source of nutrients collectively supplies 70% of the annual phosphorus loading to the lake via Hammond and Felkner Ditches which drain surrounding farm fields. Since precipitation and dry fallout phosphorus inputs are impossible to control and septic inputs are minimal, any attempts to reduce phosphorus inputs into Lake Waubee must be directed at the dominant source: agricultural fields.

Under most circumstances, runoff water exiting farmed plots transports soil particles and various chemical substances into streams draining the area. Studies have shown that 90-98% of the phosphorus lost from agricultural fields is bound to the sediment particles (Hubbard et al. 1982), except during certain winter conditions when up to 33% of the phosphorus may be in dissolved form. Obviously, any reduction in soil loss will bring about concomitant reductions in nutrient export. A management practice focusing on stabilizing

topsoil and preventing sediment loss from the fields should benefit both the farmer, by protecting his valuable soil resource, and the lake community, by reducing phosphorus loading to Lake Waubee.

The single most important land management practice that a farmer can use is no-till plowing. In consideration of local physiographic and soil characteristics, the successful implementation of this tillage method would reduce soil loss 90-95% (personal communication, Steve Boeder, Kosciusko County Soil Conservation Service Office). Since most of the phosphorus leaving the fields is associated with sediment particles, a tremendous reduction in phosphorus export would result. The farmer could retain valuable plant nutrients and soil, and the lake benefit by reduced phosphorus loading.

Admittedly, no-till agricultural practices are controversial. Farmers are reluctant to change farming techniques, especially during hard economic times. The costs of such changes are not fully documented. The results of no-till farming, however, far outweigh any negative aspects of its application. Threrfore, we strongly urge its adoption by the farmers in the Lake Waubee watershed. Site specific implementation of this practice should be done in consultation with the Kosciusko County Soil Conservation Service. They are eager to assist in any possible manner. Interested persons should contact: Steve Boeder, Kosciusko County SCS, 303 E. Gilliam, Warsaw, IN 46580 (219/267-5726) for further information.

5. Buffer Zones

Another long term strategy to reduce phosphorus loading to Lake Waubee involves the establishment of grassed "buffer zones" along Felkner and Hammond Ditches and their tributary streams. Since 70%

of the phosphorus entering the lake comes from the runoff collected by these streams, any reduction in phosphorus loading to the streams will benefit the lake.

As mentioned above, a large portion of the phosphorus entering Felkner and Hammond Ditches is associated with sediment runoff. A grassed buffer strip 7 to 10 meters wide along each stream bank would significantly reduce field soil loss. A combination of Kentucky 31 Tall Fescue and rye grass is recommended for such buffer zones (personal communication, Steve Boeder, SCS).

This management practice may also be unpopular with local farmers since it takes land out of production. However, the long term benefits of reduced soil erosion and phosphorus loading to the streams argue for its implementation.

6. Wetland Protection

Another long term strategy for nutrient reduction is the use of wetlands as a biological filter. It is well documented that the natural vegetation of wetlands serve to remove nutrients from water and "tie them up" in plant tissues. This removal is quite efficient and significant reductions in nutrient loadings to the lake can be accomplished.

It is fortunate that both Hammond and Felkner Ditches flow through wetlands before enter Lake Waubee. Felkner Ditch flows through an extensive wetland from its origin to its confluence with Lake Waubee. Our data indicate that this area greatly reduces phosphorus concentrations in the stream as it flows from Maple Leaf Farms towards the lake. Although some of the phosphorus reduction is no doubt due to

dilution of the stream water by springs, there is also a significant biological effect of the wetland. This was evidenced by the sharper reduction in Felkner stream phosphorus concentrations after plant growth began in April. A similar, but less obvious pattern, can be expected on Hammond Ditch.

Therefore, we strongly urge the protection of these wetlands on both streams as a long term management strategy. The cost of this strategy is negligible since the wetlands already exist. Every effort should be made to preserve, and if possible expand, these areas so that they can continue as efficient nutrient traps for the protection of Lake Waubee.

7. Septic System Maintenance

Our study indicates that the residential septic systems surrounding Lake Waubee are functioning properly at this time. Bacteriological surveys failed to produce indications of malfunctioning systems, and make it quite clear that Lake Waubee is perfectly safe for public recreational usage. Nutrient inputs into the lake from septic systems are also minimal in relation to other sources. However, to prevent possible future problems, we strongly urge the lake residents to undertake a periodic septic system maintenance program to insure that their systems continue working properly. Consultation with local sanitary professionals could provide specific site-by-site recommendations for this program and cost would be minimal. This approach would help preserve Lake Waubee, and prevent the development of future health problems.

8. Development Restrictions

We estimate that 50% to 60% of the shoreline of Lake Waubee has been developed for residential usage. Much of the remaining land is

in a relatively wild state, and we suggest that efforts be made to restrict further development of these regions. Lake Waubee does not appear to be over-burdened with an extensive residential population at this time, and regulated future development would prevent this situation. In addition, these marshy areas are important habitats for wildlife, and probably function as a buffer zone around the perimeter of the lake. This approach, in conjunction with the previous suggestions, would help preserve Lake Waubee for future generations.

The eight management strategies listed above have been selected for implementation on Lake Waubee. The obvious question and the one asked most frequently by the concerned citizen is: "Will these strategies work and how much of an improvement in the lake can be expected?"

This question must be answered separately for short term versus long term strategies. In the case of the three short term strategies (weed barriers, herbicides, and harvesting) the answer is quite clear. All three strategies will provide a very significant improvement in the lake (i.e. effective weed control). It must be remembered that these are only cosmetic solutions that must be repeated on a regular basis. For their designated purpose of reducing yearly weed problems, however, they will be effective.

The effects of the five long term strategies on improving Lake Waubee are a little more difficult to analyze. It is a fact that any reduction in phosphorus loading to the lake will be beneficial.

The effectiveness of each strategy depends upon the degree of phosphorus removal accomplished by that strategy.

One way to look at the postulated improvements in the water quality of Lake Waubee is to use a model developed for such purposes (Reckow and Simpson 1980). Emperically, average annual in-lake phosphorus concentrations can be predicted from the equation:

$$P = \frac{L}{11.6 + 1.2\ (q_s)} \qquad 1)$$

where

P = mean annual in-lake P concentration (mg l^{-1})

L = areal P loading (g P m^{-2} y^{-1})

q_s = areal water loading (10.98 m y^{-1})

Hence, we can look at the change in average in-lake phosphorus concentration resulting from various reductions in phosphorus removal.

The effect of reduced phosphorus loading on the phytoplankton community of Lake Waubee can also be predicted, although with much less confidence.

Emperical relationships have been developed which relate average summer chlorophyll a concentrations (an indicator of algal biomass) to average summer total phosphorus levels in the epilimnion of a lake. One commonly used equation developed by Jones and Bachmann (1976) is:

$$\log \text{Chl. } a = -1.09 + 1.46\ (\log TP) \qquad 2)$$

where

Chl. a = chlorophyll a concentration (µg l^{-1})

TP = total phosphorus concentration (µg l^{-1})

We will use this relationship cautiously in our discussion, for many lakes respond in unique manners which are not adequately described by this or other current models (Smith and Shapiro 1981).

One other parameter that will be affected by reduced phosphorus loading is Secchi disk transparency. This parameter is meaningful to lake residents, for they can visually see improvements in water clarity. Carlson (1977) emperically related Secchi depth to total phosphorus using the equation:

$$\ln SD = 3.876 - 0.98 (\ln TP) \qquad 3)$$

where

SD = Secchi depth (m)

TP = total phosphorus ($\mu g\ l^{-1}$)

This can be manipulated to produce the simple predictive equation:

$$SD = 48 \left(\frac{1}{TP}\right) \qquad 4)$$

We can use this relationship to model changes in Secchi depth as a function of total phosphorus.

The effects of various phosphorus reduction strategies on in-lake phosphorus concentration, chlorophyll a concentrations, and Secchi disk transparency are shown in Table 9.

Assuming the phosphorus values predicted from equation 1 (Table 9) to be representative of mean epilimnetic summer values, the following predictions can be made. If a 50% reduction in phosphorus input from both streams was attained, the resultant in-lake phosphorus concentration would be 20.3 $\mu g\ l^{-1}$. This would yield an average summer Secchi depth of 2.36 m, only a slight improvement over the

measured 1981 value. It would appear, therefore, that a 50% reduction in stream phosphorus loading would result in little qualitative improvement of water transparency, while a 75% reduction would increase transparency by approximately one-third. Chlorophyll a values resulting from a 75% reduction in phosphorus loading would be 4.2 $\mu g\ \ell^{-1}$, indicating a very unproductive lake with excellent water quality.

It is very difficult to predict the response of macrophyte communities to a reduction in phosphorus input, for many interrelating factors determine their growth response. However, our data suggest that the macrophytes are phosphorus limited early in the growing season, and the reduced availability of phosphorus in the water may limit their biomass production further. This would depend upon the availability of sediment phosphorus for uptake by the roots of the plants, and the efficiency with which they utilize it. Remember that shallow littoral sediments, exclusive of those directly adjacent to the Felkner Inflow, have the lowest phosphorus content of any bottom deposits in the lake basin. It is possible that the reduced availability of in-lake phosphorus could reduce macrophyte biomass in certain littoral areas of Lake Waubee.

We feel that significant changes in the condition of Lake Waubee would require at least a 50% to 75% reduction in the P loading from each stream. This would lower the mean annual P concentration by one-third to one-half, and place Lake Waubee into Vollenweider's (1968) permissible loading range. Two basic questions remain. What is the realistic probability that the degree of abatement necessary (about 75%) to elicit obvious improvements in the water quality of

TABLE 9.

Predicted response of Lake Waubee to various hypothetical reductions in phosphorus loading.

Hammond (% removed)	Felkner (% removed)	Loading ($g\ P\ m^{-2}\ y^{-1}$)	In-lake P ($\mu g\ \ell^{-1}$)	Chlor. a ($\mu g\ \ell^{-1}$)	Secchi (m)
0	0	0.770	29.6 (22.3)*	11.43 (9.37)*	1.62 (2.14)*
25	25	0.636	25.7	9.30	1.87
50	50	0.503	20.3	6.59	2.36
75	75	0.369	14.9	4.20	3.22
100	100	0.236	9.5	2.18	5.05
0	100	0.488	19.7	6.31	2.44
100	0	0.518	20.9	6.88	2.30

*measured average summer values

Lake Waubee can be obtained from these long term strategies? Furthermore, if these abatement levels cannot be reached, is it still important to make every attempt to reduce the amount of phosphorus exported from the agricultural lands in the watershed?

The answer to the first question is unclear. Admittedly, 75% is a major reduction in the phosphorus export from the watershed. However, remember that no-till agriculture and grassed waterways could reduce soil loss by over 90%, and that 90% to 98% of the phosphorus leaving farm fields is bound to these sediment particles. Hypothetically, it is possible to achieve this high level of reduction in the watershed phosphorus inputs into Lake Waubee with these two management strategies. Realistically, however, such a high level of abatement is probably not likely due to non-compliance by many farmers.

If these high abatement levels cannot be attained, is it still important to make every attempt to reduce phosphorus and soil export from agricultural lands? The answer is a strong yes! Smaller reductions might not elicit a visual improvement in the water quality of Lake Waubee, but they definitely will help preserve existing water quality and prevent further degradation of the lake system in the future. Since Lake Waubee is a net sink for phosphorus inputs, any reduction in phosphorus loading would help to slow the natural eutrophication process. Lake Waubee currently has good water quality, and in order to protect that water quality every effort should be made to reduce phosphorus loading by utilizing the long-term management strategies proposed in this report.

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APPENDICIES

APPENDIX I

METHODOLOGY

Procedure 1. Program for calculating stream flow.

```
      DIMENSION X(25),DEPTH(25),FLOW(25),LOC(6),LDATE(2)
      WRITE(5,91)
      READ(5,92) (LOC(I),I=1,6)
      WRITE(5,93)
      READ(5,94) (LDATE(I),I=1,2)
      WRITE(5,95)
      READ(5,96) STAFF
      WRITE(5,101)
      READ(5,102) WIDTH
      K=INT(WIDTH/0.25)
      X(1)=0.0
      DEPTH(1)=0.0
      FLOW(1)=0.0
      X(K)=0.0
      DEPTH(K)=0.0
      FLOW(K)=0.0
      TFLOW=0.0
      DO 10 J=2,K
      X(J)=X(J-1)+0.25
      WRITE(5,103) X(J)
      WRITE(5,104)
      READ(5,105) DEPTH(J)
      DEPTH(J)=DEPTH(J)/100.
      WRITE(5,106)
      READ(5,107) FLOW(J)
      FLOW(J)=FLOW(J)*0.3048
      FFLOW=FLOW(J)*DEPTH(J)*0.25
      TFLOW=TFLOW+FFLOW
   10 CONTINUE
C
C **** OUTPUT RESULTS  ****
C
      PAUSE'ADJUST PAPER TO TOP OF NEXT PAGE'
      WRITE(5,99)
      WRITE(5,97)(LOC(I),I=1,6),(LDATE(I),I=1,2)
      WRITE(5,98) STAFF, TFLOW
      WRITE(5,99)
      WRITE(5,99)
      WRITE(5,99)
      WRITE(5,99)
   91 FORMAT(1H+,2X,'LAKE NAME:? ',$)
   92 FORMAT(6A4)
   93 FORMAT(1H+,2X,'DATE:? ',$)
   94 FORMAT(2A4)
   95 FORMAT(1H+,3X,'STAFF GAUGE READING:? ',$)
   96 FORMAT(F5.1)
   97 FORMAT(25X,'STREAM FLOW'/26X,6A4/28X,2A4//)
   98 FORMAT(4X,'STAFF GAUGE READING: ',F5.1,5X,'STREAM
     1FLOW (M3/SEC): ',1PE8.2)
   99 FORMAT(1X,////)
  101 FORMAT(4X,'STREAM WIDTH (IN M ) IS:? ')
  102 FORMAT(F5.2)
  103 FORMAT(2X,'WIDTH',F5.2,' M')
  104 FORMAT(4X,'DEPTH (IN CM) :? ',$)
  105 FORMAT(F5.1)
  106 FORMAT(1H+,4X,'FLOW (IN FT./SEC):? ',$)
  107 FORMAT(F5.2)
      STOP
      END
```

Procedure 2a

PHOSPHORUS REAGENTS

REAGENTS:

1. Sulfuric acid, 5N
   bring 140 mls. conc. H_2SO_4 to 1 liter with distilled H_2O.

   Sulfuric acid, 10.8N (for digesting)
   bring 300 mls. conc. H_2SO_4 to 1 liter with distilled H_2O.

   *ALWAYS ADD ACID TO WATER
2. Antimony potassium tartrate
   dissolve 4.39 gm. of $K(SbO)C_4H_4O_6 \cdot 1/2\ H_2O$ in 200 ml. distilled H_2O. --- Store in a dark bottle at 4° C.

3. Ammonium molybdate
   dissolve 20 gm. of $(NH_4)_6Mo_7O_{24} \cdot 4\ H_2O$ in 500 ml. distilled water. --- Store in a plastic bottle at 4 C.

4. Ascorbic acid, 0.1M
   dissolve 1.76 gm. of ascorbic acid in 100 ml. distilled H_2O. --- Stable for about one week at 4 C.

5. Hydrochloric acid, 1N
   bring 84 ml. conc. HCl to 1 liter with distilled H_2O.

6. Sodium hydroxide, 10N
   dissolve 400 gm. NaOH into 1 liter of distilled H_2O.

7. Phenolphthalein indicator
   dissolve 5 gm. of phenolphthalein in 500 ml. 95% ethyl or isoprophyl alcohol and add 500 ml. distilled H_2O.

8. Potassium persulfate
   dissolve 5 gm. $K_2S_2O_8$ in 100 ml distilled H_2O.

9. Phosphorus solution, 0.25 umoles/ml
   dissolve 33.99 mg. KH_2PO_4 in 1 liter of distilled H_2O.

10. Phosphate color reagent
    1-50 ml. 5N H_2SO_4
    2-5 ml. Antimony potassium tartrate
    3-15 ml. Ammonium molybdate
    4-30 ml. Ascorbic acid (good for only 7 days)

    mix the above reagents carefully. The color reagent is stable for 1 week when stored at 4 C. Should the color reagent become cloudy; heat gently till transparent.

Procedure 2b

TOTAL PO_4

1. Add 50 ml. of lake water to a 125 erhlenmeyer flask. (Run standard at the same time; see note #)
2. Add 7.5 ml persulfate solution and 0.5 ml. H_2SO_4. 10.8N.
3. Cover flask with a 50 ml. beaker and autoclave for 1 hour.
4. After samples have cooled, add 2 drops phenolphthalein indicator.
5. Add 10N NaOh dropwise until indicator turns pink.
6. Add 1N HCl dropwise until pink color just disappears.
7. Add 5.0 ml. of phosphate color reagent and allow at least 10 minutes for color development (color is stable for up to 1 hour).
8. Read at 880 mu against blank *, and record.

#Standards (0.5, 0.25, 0.15, and 0.10 umoles P) are prepared by adding 2.0, 1.0, 0.6, and 0.4 mls. of a 0.25 umoles P/ml stock solution to 4 flasks. Each flask is then brought to 50 mls. by adding deionized H_2O. Standards are analyzed in exactly the same manner as the unknowns.

*A blank is prepared exactly as a sample except that no phosphate reagent (step #7) is added. —— A turbidity blank (TBl) may be run against a deionized H_2O blank; then the deion. blank should be run against unknowns. Then turbidity value can be subtracted.—— Standards may also read against deion. blank.

Procedure 2c

SOLUBLE REACTIVE PHOSPHORUS

1. Add 50 mls. of filtered lake[U] water to a 125 erhlenmeyer flask.*
2. Add 5m. of phosphate reagent and mix at once. Allow 10 minutes for color development.
3. Read at 880 against blank.**

*Standards (0.25, 0.125, 0.063 and 0.05 umoles P) are prepared by adding 2.0, 1.0, 0.6, and 0.4 ml. of 0.125 umole/ml. stock solution to four flasks and bringing volume to 50 ml. with deionized water. Standards are analyzed exactly as unknowns.

**A blank is prepared exactly as a sample except that no phosphate reagent is added.

U Water should be filtered through washed filters (i.e.-filters that have been thoroughly rinsed with PO_4 free water).

Procedure 3

AMMONIA

REAGENTS:

A. Solution A

Dissolve 10.0 g of phenol (carbolic acid) and 0.05 g of sodium nitroferricyanide in deionized water and bring to 1 l volume.

B. Solution B

Dissolve 5.0 g of sodium hydroxide and 0.42 of sodium hypochlorite (= 8.4 ml. of bleach) in deionized water and bring to 1 l volume.

C. Ammonia Solution

Stock solution 1 umole NH_3/ml

Dissolve 62.27 mg of $(NH_4)_2SO_4$ in deionized water and bring to exactly 1 l.

Standard solution 0.10 umoles NH_3/ml

Add 100 ml. of the Stock ammonia solution to 1 l flask and bring to volume with deionized water.

PROCEDURE:

1. Add 50 ml. of unfiltered water sample to a 125 erhlenmeyer flask. #
2. Raise pH with 3N NaOH to between 5 and 7.
3. Add 5.0 ml. of Solution I and 5.0 ml. of Solution II.
4. Cover with a 50 ml. beaker and let stand at room temperature for 4 hours for color development (color is stable for 24 hours).
5. Read at 625 mu against blank * and record.

Standards (0.50, 0.25, 0.15, and 0.10 umoles NH_3) are prepared by adding 5.0, 2.5 1.5, and 1.0 ml. of a 0.10 umole NH_3/ml. standard solution to each of four volumetric flasks. Each flask is then brought to 50 ml. by adding deionized water. Standards are analyzed exactly as unknowns.

* A blank is prepared exactly as a sample except that 50 ml. of deionized water is used instead of 50 ml. of water sample.

REFERENCES:

Chaney, A. L. and E. P. Marboch. 1962. Modified reagents for determination of urea and ammonia. Clinical Chemistry 8(2):130-132.

NITRITE

REAGENTS:

1. Ammonium hydroxide, concentrated.

2. Ammonium chloride - EDTA solution.
   dissolve 13 g ammonium chloride and 1.7 g of disodium ethylenediamine tetracetate in 900 ml deionized water. Adjust the pH to 8.5 with concentrated ammonium hydroxide and dilute to 1 liter with deionized water.

3. Color reagent.
   dissolve 10 g sulfanilamide and 1 g N (1-naphthyl)-ethylene-diamine dihydrochloride in a mixture of 100 ml concentrated phosphoric acid and 800 ml of deionized water and dilute to 1 liter with deionized water.

4. Stock Nitrite solution 1.0 ml = 1.00 mg NO_2-N.
   dissolve 6.072 g KNO_2 in 500 ml deionized water and dilute to 1 liter. Preserve with 2 ml of chloroform and refrigerate. Stable for approximately 3 months.

5. Standard Nitrite solution 1.0 ml = 0.01 mg NO_2-N.
   dilute 10.0 ml of stock nitrite solution to 1 liter using deionized water.

PROCEDURES:

1. Add 25.0 ml water sample to 75.0 ml ammonium chloride-EDTA solution in 125 ml erhlenmeyer flask.*

2. Mix well and add 4.0 ml of color reagent to sample.

3. Allow 10 minutes for color development and read spectrophotometrically against blank.# at 540 nm. Color is stable for 2 hours.

* Standards (1.786, 0.893, 0.357, 0.179, and 0.089 umoles NO_2) are prepared by adding 10.0, 5.0, 2.0, and 1.0 and 0.5 ml standard solution to 50 ml deionized water and bringing to volume in 100 ml volumetric flasks. A 25 ml aliquot is then removed and analyzed exactly as unknowns.

\# A blank is prepared exactly as sample except that 25.0 ml of deionized water is used instead of water sample.

REFERENCES:

Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes.

Procedure 5

NITRATE

REAGENTS:

1. Granulated cadmium: 40-60 mesh (E. M. Laboratories, Inc., 500 Exec. Blvd., Elmsford, NY 10523, Cat. 2001 Cadmium, Coarse Powder).

2. Copper-Cadmium: The cadmium granules (new or used) are cleaned with dilute HCl and copperized with 2% solution of copper sulfate in the following manner:

   A. Wash the cadmium with dilute HCl and rinse with deionized water. The color of the cadmium should be silver.

   B. Swirl 25 g cadmium in 100 ml portions of a 2% solution of copper sulfate for 5 minutes or until blue color partially fades, decant and repeat with fresh copper sulfate until a brown colloidal precipitate forms.

   C. Wash the copper-cadmium with deionized water (at least 10 times) to remove all the precipitated copper. The color of the cadmium so treated should be black.

3. Preparation of reduction column.

   A. Insert glass wool plug into bottom of 50 ml buret (1 cm I.D.) Fill with deionized water. Add sufficient copper-cadmium granules to produce column 15 cm in length. Maintain liquid level above granules to avoid entrapment of air. Wash the column with 200 ml of dilute ammonium chloride-EDTA solution. Place 100 ml glass funnel atop column to assist in the addition of the sample to the buret. Activate the column by passing 100 ml of a solution composed of 25 ml of 1.786 umole NO_3 standard and 75 ml of ammonium chloride-EDTA solution. Use flow rate of 7 to 10 ml per minute.

4. Ammonium hydroxide, conc.

5. Dilute hydrochloric acid, 6N: Dilute 50 ml of conc. HCl to 100 ml with deionized water.

6. Copper sulfate solution, 2%: Dissolve 20 g of $CuSO_4 \cdot 5H_2O$ in 500 ml of deionized water and dilute to 1 liter.

7. Ammonium chloride-EDTA solution: Dissolve 13 g ammonium chloride and 1.7 g disodium ethylenediamine tetracetate in 900 ml of deionized water. Adjust the pH to 8.5 with conc. ammonium hydroxide and dilute to 1 liter.

8. Dilute ammonium chloride-EDTA solution: Dilute 300 ml of ammonium chloride-EDTA solution to 500 ml with deionized water.

9. Color reagent: Dissolve 10 g sulfanilamide and 1 g n(1-naphthyl)-ethylene-diamine dihydrochloride in a mixture of 100 ml conc. phosphoric acid and 800 ml of deionized water and dilute to 1 liter with deionized water.

10. Stock nitrate solution: Dissolve 7218 g KNO_3 in deionized water and dilute to 1000 ml. Preserve with 2 ml of chloroform per liter. This solution is stable for at least 6 months. 1.0 ml = 1.00 mg NO_3-N.

11. Standard nitrate solution: Dilute 10.0 ml of nitrate stock solution to 1000 ml with deionized water. 1.0 ml = 0.01 mg NO_3-N.

PROCEDURES:

1. Add 25.0 ml water sample to 75.0 ml ammonium chloride-EDTA solution in 125 erhlenmeyer flask.*

2. Pour sample into reduction column and collect at rate of 7 to 10 ml per minute.

3. Discard the first 40 ml and collect 25.0 ml in a volumetric flask.

4. Pour reduced sample into flask and add 1.0 ml of color reagent. Reduced samples should not stand longer than 15 minutes before the addition of color reagent.

5. After 10 minutes but before 2 hours, read the absorbance spectrophotometrically at 540 nm against a blank # and record.

* Standards (1.786, 0.893, 0.357, 0.179, and 0.089 umoles NO_3) are prepared by adding 10.0, 5.0, 2.0, 1.0 and 0.5 ml of standard NO_3 solution to 50 ml deionized water and diluting to 100 ml in volumetric flask. A 25.0 ml aliquot is added to 75.0 of ammonium chloride-EDTA and is analyzed exactly as an unknown.

\# A blank is prepared exactly as a sample except that 25.0 ml of deionized water is used.

NOTES ON THE USE OF THE REDUCTION COLUMN:

1. Between samples, run 100 ml of deionized water through column before adding next sample.

2. After all samples are reduced, wash the column with deionized water and fill the buret with dilute ammonium chloride-EDTA solution for storage. Cover with parafilm to prevent evaporation.

3. A well trained technician can operate three columns at a time.

Procedure 5 (con't.)

4. The reduction response of each column should be determined initially by running a complete standard curve through each column and comparing the resulting slopes for significant differences. All columns should yield the same response.

5. Periodically recharge the cadmium and repack the columns. Recheck the responses of each column at this time.

6. When processing standards during normal operation, it is best to randomly assign each standard to a different column.

7. Do not allow air to become trapped in the cadmium granules.

REFERENCES:

Environmental Protection Agency. 1979. Methods for the chemical analysis of water and wastes.

TOTAL ORGANIC NITROGEN

REAGENTS:

1. Phenol-alcohol solution

   dissolve 10.0 g of reagent grade phenol in 100 ml. of 95% v/v ethyl alcohol USP.

2. Sodium nitroprusside 0.5%

   dissolve 1.0 g of sodium nitroprusside (nitroferricyanide) in 200 ml. water. Store in amber bottle for maximum of 30 days.

3. Alkaline solution

   dissolve 100.0 g of trisodium citrate and 5.0 g sodium hydroxide in 500 ml water.

4. Sodium hypochlorite

   use commercial hypochlorite (e.g. Chlorox) which should be at least 1.5 N (decomposes).

5. Oxidizing solution

   mix 100.0 ml alkaline solution with 25.0 ml of sodium hypochlorite solution. Use the same day.

6. Nitrogen stock solution 1 mM/ml

   dissolve 66.06 g ammonium sulfate in 900 ml organic-free deionized water and bring to 1 l.

7. Nitrogen standard solution 2.5 uM/ml

   dissolve 2.5 ml of N stock solution in 900 ml organic-free deionized water and bring to 1 l.

PROCEDURES:

1. *Place 25 ml of lake water into a 125 ml Erlenmeyer flask.
2. Add 1.0 g potassium persulfate ($K_2S_2O_8$).
3. Cover with 50 ml beaker and autoclave at 121° C and 15 psi for 1 hr.
4. Remove and cool to room temperature.
5. Add 0.5 g DeVarda's Alloy to each flask and allow them to sit for 24 hrs. This step is important.
6. Swirl flask gently and remove 1.0 ml aliquot with automatic pipett.

Procedure 6 (con't.)

7. Dilute to 25.0 ml volume using deionized water and pour into clean 50 ml beaker.

8. Add 3 drops of 3N NaOH to sample. Check pH with meter. Add 1 N NaOH dropwise until pH is approximately 5.0 (the addition of 1 N NaOH may not be necessary).

9. Add 1.0 ml. of phenol-alcohol solution, 1.0 ml of sodium nitroprusside solution, and 2.5 ml of oxidizing solution to each sample in rapid succession.

10. Read spectrophotometrically after 1 h at 640 nm.

* Standard preparation: Prepare standard curve in triplicate of 7.5, 5.0, 2.5, and 1.25 uM by bringing 3.0, 2.0, 1.0 and 0.5 ml of 2.5 uM/m/$(NH_4)_2SO_4$ standard solution to 25 ml in volumetric flask with N-free Insta-pure (Baker) water. Standards are analyzed exactly as unknowns.

NOTE: The value obtained from the standard curve must be corrected for trace amounts of NO_2, NO_3, and NH_3 with the following equation:

Total Organic N = A - (.04 x $((NO_2) + (NO_3) + (NH_3))$)

Where A = value from standard curve
(all concentration values in uM/l)

REFERENCES:

Raveh, A. and Y. Avnimelech. 1979. Total nitrogen analysis in water, soil and plant material with persulfate oxidation. Water Res. 13:911-912.

Solorzano, L. 1969. Determination of ammonia in natural water by the phenol hypochlorite method. Limnol. Oceano. 14:799.

REACTIVE SILICA

REAGENTS:

A. Solution A — 6N HCl

to approximately 400 ml. of deionized water, carefully add 500 ml. of concentrated HCl. Cool, and bring volume to exactly 1000 ml. Store in plastic container.

B. Solution B — Ammonium molybdate

dissolve 50.0 g $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$ in approximately 400 ml distilled water. Bring to exactly 500 ml. and store in a plastic container.

C. Solution C — Oxilic acid

dissolve 50.0 g $H_2C_2O_4\cdot 2H_2O$ in approximately 400 ml. distilled water. Bring to exactly 500 ml. and store in a plastic container.

D. Silica solutions

Stock solution — 20 umoles/ml
dissolve 5.68 g $Na_2SiO_3\cdot 9H_2O$ in recently boiled and cooled distilled water. Bring volume to exactly 1000 ml. and store tightly capped in a plastic container.

Standard solution - 1 umole/ml
dilute 5.0 ml stock silica solution to 100.0 ml. with freshly boiled and cooled distilled water.

PROCEDURE:

1. To 50.0 ml of filtered water #Ψ add in rapid succession
   a) 1.0 ml. solution A
   b) 2.0 ml. solution B
2. Mix well and allow the solution to stand for 5 to 10 minutes.
3. Add 1.5 ml. oxilic acid solution and mix well.
4. Read the color after 2 minutes but before 15 minutes at 410 nm against a distilled water blank.*

\# IMPORTANT: Filter through millipore, not glass fiber, filters!!!

Ψ Standards (0.4, 0.6, 1.0, 2.0 umole SiO_2) are prepared by adding 0.4, 0.6, 1.0, and 2.0 ml of the standard silica solution to each of four flasks. Each flask is then brought to 50 ml by addition of deionized water. Standards are analyzed exactly as unknowns.

* Prepare a reagent blank by adding 50 ml. of deionized water to a flask and analyzing. This gives background (reagent) contamination. These O.D. values are subtracted from the standard curve O.D. values only. Prepare a turbidity blank by adding 50 ml. filtered sample to a flask, and omitting color reagents.

NOTE:

All flasks graduate cylinders, etc. must not be glass. Polycarbonate or other plastic labware should be used.

Procedure 8

RESIDUE

APPARATUS:

1. 100 ml porcelain crucibles.
2. Drying oven.
3. Muffle furance.

PROCEDURE:

1. Clean, ash, and pre-weigh crucible.
2. Add 150 ml water sample (2 aliquots of 75 ml) to crucible and evaporate to dryness at 98° C in drying oven for 24 hours.
3. Remove, cool in dessicator, and obtain dry weight.
4. Place into muffle furnace and ash at 550° C for 1 hour.
5. Remove, cool in dessicator, and record ash weight.

CALCULATIONS:

$$\text{Total Residue (mg/l)} = \frac{(A - B) \times 1000}{C}$$

Where A = dry weight of sample + dish (mg)
B = dry weight of dish (mg)
C = volume of sample (ml)

A similar calculation is performed using ash weight.

CONCENTRATIONS OF PARTICULATE MATERIAL IN LAKE WATER

The concentrations of particulate material larger than 1μ diameter may be estimated from the weight of the material retained by glass fiber filters.

PROCEDURES:

Preheat on electric muffle furnace until the temperature is stable at 500° C. Place a required number of glass fiber filters in individual folded squares of aluminum foil, number the foil squares,[1] and put them in the oven for 1 hr. to ignite any residual organic material on the filters. Remove the folded foil squares and their filters from the oven and cool to room temperature in a dessicator. Weight each filter to the nearest 0.1 mg. (The filters will be brittle after heating and they should be handled with flat-bladed forceps, so as not to contaminate them.)

To filter a water sample, place a filter on a filter base fitted to a vacuum filtration flask. Moisten the filter with a few ml. of water from a wash bottle, attach the filtration funnel, and filter a measured volume of water. Dismantle the filtration assembly, remove the filter with a forceps, fold it in half, and put it in its numbered foil square.[2] Put the folded foil square with its filter in a drying oven for 1 hr. at 101° C.[3] Cool to room temperature in a dessicator and weigh the filter to the nearest 0.1 mg.

Put the filter back into its folded foil square and heat it in the muffle furnace of 1 hr. at 500° C. to ignite the organic material. Remove from the oven, cool, and weight.[4]

CALCULATIONS:

Calculate the concentrations of particulate material using the following equations.

1. particulate material/liter (W_P):

$$W_P = \frac{W_{101} - W_f}{V_f}$$

2. particulate organic material/liter (W_o):

$$W_o = \frac{W_{101} - W_{500}}{V_f}$$

3. particulate inorganic material (ash/liter (W_1):

$$W_1 = W_P - W_o$$

Where W_f = weight of the filter

W_{101} = weight of the filter after filtration and heating of 60° C

W_{500} = weight of the filter after heating at 500°

V_f = volume of water filtered (l)

Procedure 9 (con't.)

FOOTNOTES:

1. The aluminum foil squares can be best numbered with a ball-point pen. Although the ink will be burned off, the impression of the number will remain readable. It is a good idea to number the pieces of foil in several places.

2. When placing the wet filter back into the foil packet, place a small slip of paper under the filter to prevent it from sticking to the foil when drying.

3. Samples may be left at 101° C. for an indeterminate length of time. It may take more than one hour for the filters to dry to a constant weight.

4. All dried filters are very hydroscopic and will absorb moisture rapidly. To assure the best results, therefore, filters should be kept in the dessicator at all times except when weighing.

TOTAL ALKALINITY

REAGENTS:

1. Sulfuric Acid 1.0 N
   dissolve 28.0 ml of concentrated H_2SO_4 (36 N) in about 900 ml of deionized water. Bring to exactly 1 liter volume.

2. Sulfuric Acid 0.02 N
   dissolve 20.0 ml of 1.0 N H_2SO_4 in about 900 ml of deionized water. Bring to exactly 1 liter volume.

PROCEDURE:

1. add 50.0 ml of water sample to small beaker with magnetic stir bar in place
2. insert calibrated pH probe and stir on magnetic stir plate
3. titrate with 0.02 N H_2SO_4 until pH reaches 4.8
4. record ml of titrant used

CALCULATIONS:

$$\text{Total Alkalinity (mg/l as } CaCO_3) = \frac{(A) \times (B \times 50{,}000)}{C}$$

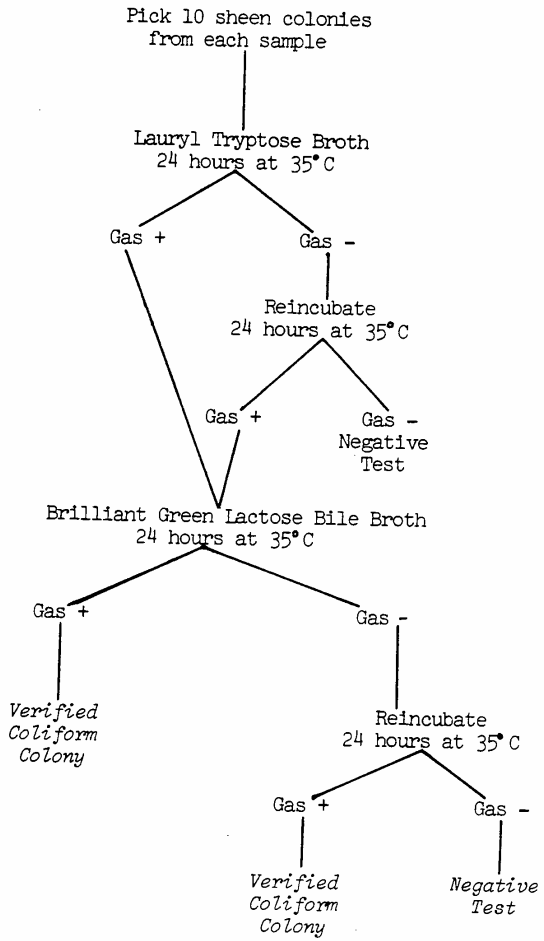
where: A = total volume of acid titrant used
B = normality of acid
C = volume of sample (ml)

REFERENCES:

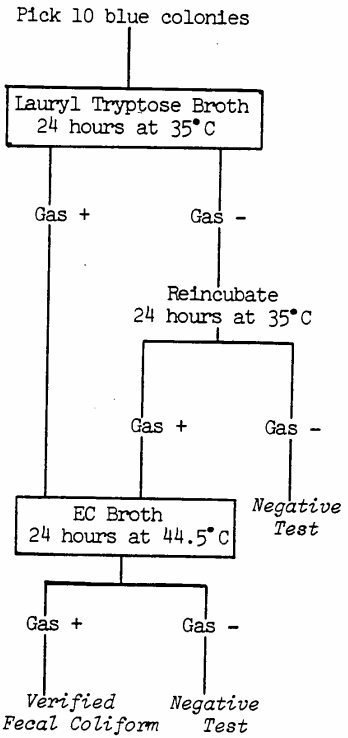
Wetzel, R.G. and G.E. Likens. 1979. Limnological analyses. W.B. Saunders Co. 357 pp.

Procedure 11a

TOTAL COLIFORMS

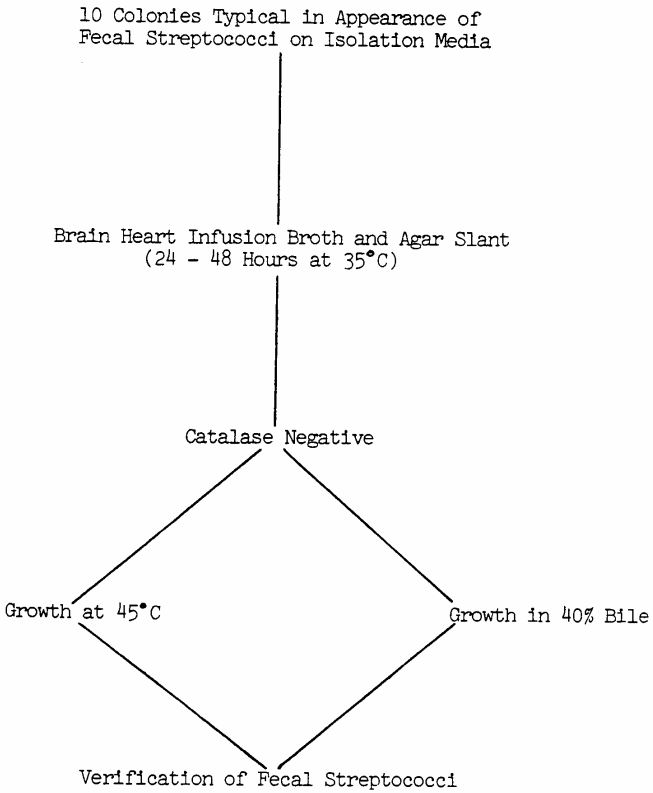


FECAL COLIFORMS



Procedure 11c

FECAL STREPTOCOCCI



CHLOROPHYLL a ANALYSIS

PROCEDURE:

1. Filter algae onto 0.45 filters (either glass fiber or millipore filters). Record the volume filtered (ml).*
2. Grind filter in 90% acetone. Transfer to a numbered centrifuge tube and add acetone to bring to volume. Record the volume of acetone (ml).
3. Place in the dark for 10 minutes to extract.
4. Shake the tube and place in the centrifuge. Centrifuge for 10 minutes.
5. Transfer the supernatent to a 1.0 cm spectrophotometer cell.
6. Read and record the optical density at 750, 665, 663, 645, and 630 mu. At each wavelength the spectrophotometer must be zeroed using an acetone blank.
7. Add 2 drops of 1N HCl to sample and blank. Read and record the optical density at 750 and 665 mu.
8. Calculate the amount of chlorophyll a and phaeo-pigments as follows:

   a) Scor-Unesco Trichomatic Equations

   $$\text{chl a} = (\text{ug/l}) = \frac{(11.64 \cdot E^{b}_{663} - 2.16 \cdot E^{b}_{645} + 0.10 \cdot E^{b}_{630}) \cdot v}{(V/1000 \cdot l)}$$

   b) Lorenzen's Equations

   $$\text{chl a (ug/l)} = \frac{26.7 \cdot (E^{b}_{665} - E^{a}_{665}) \cdot v}{(V/1000) \times l}$$

   $$\text{Phaeo-pigments (ug/l)} = \frac{26.7 \times (1.7\,(E^{a}_{665}) - E^{b}_{665}) \times v}{(V/1000) \times l}$$

Where: E_{663}, E_{665}, E_{645}, and E_{630} are corrected absorbances (i.e. - after subtracting 750 mu reading.

v = volume of acetone (ml)

V = volume of water filtered (ml)

l = path length of cuvette (cm)

a = after acid

b = before acid

Procedure 12 (con't.)

REFERENCES:

Lorenzen, C. J. 1967. Determination of chlorophyll and phaeopigments: Spectrophotometric Equations. Limnol. and Oceanogr. 12:335-338.

Strickland, J. D. H. and T. R. Parsons. 1972. A practical handbook of sea water and analysis. Bull. of Fisheries Res. Board Can. 167. 2nd ed. 310 pp.

* If you are unable to analyze the samples immediately, they may be stored at 4° C in the dark for up to a week without significant change in chlorophyll a. This should be checked out, however, for your own satisfaction. Freezing is not a good method of storage because it appears to destroy the porphyrin ring which causes significant changes in chlorophyll a concentrations.

ALGAL ASSAY PROCEDURE

NOTE: Maintain aseptic conditions as much as possible throughout experiment. Autoclave equipment and make transfers and inoculations in sterile transfer room.

EQUIPMENT AND GLASSWARE PREPARATION - PREPARE, AUTOCLAVE, AND LABEL

1. Appropriate number of 250 ml Erlenmeyer flasks.
2. Sample jugs.
3. E.P.A. Artificial Nutrient Media. (plus 4-6 250 ml flasks with 150 ml.)
4. E.P.A. K_2HPO_4-Free Nutrient Media.
5. (3) 250 ml Erlenmeyer flasks with 50 ml of K_2HPO_4-free media.
6. (3) 900 ml beakers.
7. (15-20) large (50 ml) centrifugation tubes.
8. 10 ml and 1 ml pipette tips.
9. Nutrient spikes A, B, & C.
10. (4-6) 50-100 ml beakers.
11. (2) 4ℓ filter flasks.
12. (2) Gelman Filter Tops (with sterile filters).
13. (4-6) 1ℓ flasks.
14. (4-5) 250 ml graduate cylinders.

MOTHER CULTURE PREPARATION

1. Transfer 7-10 day old cultures (4-6 150 ml E.P.A. culture flasks) into sterile 50 ml centrifuge tubes.
2. Centrifuge @ 2000 RPM for 1-2 minutes.
3. Decant down to 10 ml, resuspend pellet with vortex mixer in P-free media, and recentrifuge.
4. Decant, resuspend pellet, and pour into P-free media flask.
5. Rinse centrifuge tube with P-free media.
6. Starve for 24 hrs.

TEST WATER COLLECTION

1. Fill jugs with epilimnetic water, exclude air, cap, and chill.

TEST WATER PREPARATION

1. Pour in 1ℓ flasks.
2. Autoclave at 121° C and 15 p.s.i. for 30 minutes. Remove and cool.
3. Filter.
4. Pour into beakers.

Procedure 13 (con't.)

5. Pour into 250 ml graduate cylinder.
6. Pour into flasks (150 ml).
7. Allow to CO_2 equilibration for 24 hours. Shake.

TEST WATER NUTRIENT SPIKES

1. Autoclave nutrient spikes A, B & C.
2. Add appropriate spike volume to respective flasks.

INOCULUM PREPARATION

1. Count P-starved mother culture (triplicates of different volumes).
2. Adjust mother culture to correct density so that 1-2 ml of mother culture diluted to 150 ml yields ca 1000 cells ml^{-1}.
3. Add appropriate volume to each flask (Test & Controls).
4. Incubate for 14 days, shaking once per day.

BIOMASS MEASUREMENT

1. Gravimetric (Method II)
   A. Dry appropriate number of filters (0.45 µm Millipore-Type BD) for 2 hours @ 70° C (not more than 75° C).
   B. Cool filters in dessicator for 1 hour before weighing.
   C. Filter a suitable measured aliquot of culture.
   D. Rinse the filter funnel with distilled H_2O.
   E. Dry the filter to constant weight @ 70° C, cool for 1 hour in a desiccator, obtain weight.
2. Cell Counts
   A. Count a measured aliquot of culture (triplicates of different volumes).

NUTRIENT ADDITION
EXPERIMENTAL DESIGN

Treatment	Conc.	Flask Conc.	Additions
Lake H_2O + 1	0.05 mg P/l	0.0075 mg/150 ml	Add 1 ml of Sol. A.
Lake H_2O + 2	1.00 mg N/l	0.15 mg/150 ml	Add 1 ml of Sol. B.
Lake H_2O + 3	0.05 mg P/l + 1.00 mg N/l	.0075 mg/150 ml + 0.15 mg/150 ml	Add 1 ml of Sol. A. + Add 1 ml of Sol. B.
Lake H_2O + 4	1.00 mg Na_2 EDTA/l	0.15 mg/150 ml	Add 1 ml of Sol. C.
Lake H_2O + 5	0.05 mg P/l + 1.00 mg Na_2 EDTA/l	0.0075 mg/150 ml + 0.15 mg/150 ml	Add 1 ml of Sol. A. + Add 1 ml of Sol. C.
Lake H_2O + 6	1.00 mg N/l + 1.00 mg Na_2 EDTA/l	0.15 mg/150 ml + 0.15 mg/150 ml	Add 1 ml of Sol. B. + Add 1 ml of Sol. C.
Lake H_2O + 7	0.05 mg P/l + 1.00 mg N/l + 1.00 mg Na_2 EDTA/l	0.0075 mg/150 ml + 0.15 mg/150 ml + 0.15 mg/150 ml	Add 1 ml of Sol. A. + Add 1 ml of Sol. B. + Add 1 ml of Sol. C.
8	Synthetic Algal Nutrient Medium Control		
9	Test Lake Water Control		

Sol. A. is 0.0075 mg P/ml K_2HPO_4

Sol. B. is 0.15 mg N/ml $NaNO_3$

Sol. C. is 0.15 mg Na_2 EDTA/ml Na_2 EDTA

Procedure 14a

TOTAL PHOSPHORUS (MACROPHYTE)

REAGENTS

1. See procedure 2a.

METHOD

1. Grind the dried plant tissue with a mortar and pestle.
2. Place it into a marked vial and return to drying oven for 24 hours.
3. Place 100-150 mg of sample into 125 ml flask containing 50 ml deionized water. Record exact weight used on label.
4. Add 7.5 ml of potassium persulfate digest solutions (wash down the particles from the side of the flask with the addition).
5. Autoclave for 1 hour at 15 p.s.i. and 121° C.
6. Remove and cool to room temperature.
7. Carefully, avoiding particulate material, remove 20 ml of supernatent with an autopipet and place into a 50 ml beaker.
8. Carefully remove small amount of clear liquid and read on a spectrophotometer at 880 nm in a 1 cm cell for background turbidity level (absorbance) and record.
9. Adjust pH of a 20 ml sample removed from the original flask by first adding 2.0 drops of phenalphthalein indicator.
10. Add 10 N NaOH Dropwise until indicator turns pink.
11. Add 1 N HCl Dropwise until pink color just disappears.
12. Add 5.0 ml of phosphate color reagent and allow at least 10 minutes for color development (color is stable for 1 hour).
13. Read at 880 nm against a deionized water blank and record (a blank is prepared exactly as a sample except that no phosphate reagent is added.

STANDARD PREPARATION

1. See procedure 2b.

TOTAL NITROGEN (MACROPHYTE)

REAGENTS

1. See procedure 6.

METHOD

1. Grind dried plant tissue with mortar and pestle.
2. Place into marked vial and return to drying oven for 24 hours.
3. Place 100-150 mg into 125 ml flask containing 50 ml deionized water (Record exact weight used on label).
4. Carefully add exactly 25.0 ml deionized water. Avoid getting plant tissue on the side of the flask.
5. Add 1.0 g of potassium persulfate.
6. Autoclave for 1 hour at 15 p.s.i. and 121° C.
7. Remove and cool to room temperature and add 0.5 g of Devarda's alloy.
8. Allow to stand for 24 hours.
9. Place approximately 10.0 ml of sample liquid in a small centrifuge tube and centrifuge for 3 minutes at approximately 2000 r.p.m.
10. Carefully remove 1 ml of supernatent with an automatic pipette.
11. Place a 1 ml subsample into 24 ml deionized (1 in 25 dil.). Add 3 drops of 3N NaOH to each flask. Check pH. The pH should be approximately 5.0. If it isn't, adjust dropwise with 1N NaOH and swirl.
12. Add 1.0 ml of Solorzano phenol sol., 1.0 ml of sodium nitroprusside, and 2.5 ml of oxidizing reagent to each beaker.
13. Color development can be read spectrophotometrically after 1 hour at 640 nm.

STANDARD PREPARATION

1. See procedure 6.

Procedure 15

SEDIMENT ANALYSIS

FIELD PROCEDURES

1. Collect sediment and interstitial water in acid-cleaned glass jars using scuba techniques.
2. Immediately add 1.5 ml 10.8 N H_2SO_4 to samples collected for nutrient analysis.
   A. Do not add acid to samples collected for gravimetric analysis of moisture, inorganic, and organic content.
3. Place samples on ice for transportation to laboratory.

Laboratory Procedures

ANALYSIS OF TOTAL PHOSPHORUS IN INTERSTITIAL WATER

1. Allow acidified sediment samples to stand overnight under refrigeration to allow particulate material to settle out.
2. Carefully remove 50.0 ml of the overlying water with a 50 ml volumetric pipette - do not disturb sediments!
3. Carry out total P analysis using the persulfate digestion method with the following modifications:
   A. After autoclaving the samples, allow them to stand unagitated during cooling and carefully remove 20.0 ml of supernatent with autopipette (avoid particulate matter accumulated on bottom of flask).
   B. Transfer 20.0 ml subsample to 50 ml beaker, adjust pH, and add 2.0 ml phosphate color reagent - after 10 minutes, analyze spectrophotometrically at 880 nm.
   C. Triplicate selected samples for statistical analysis.

ANALYSIS OF ACID-NONLABILE SEDIMENT BOUND PHOSPHORUS

1. Decant overlying water and homogenize sediments with spatula.
2. Place portion in crucible and dry in drying oven at 101° C for 24 h.
3. Prior to removal, grind each dried sample with mortar and pestle to obtain a homogeneous powder.
4. Replace in drying oven for 2 h to ensure complete dehydration.
5. Remove subsample of 100 to 150 mg dry sediment (record exact weight!) and add to 125 ml flask containing 50.0 ml deionized water.
6. Carefully shake flask to wet sediments completely.
7. Slowly add 7.5 ml potassium persulfate solution, washing sediment particles from inside of flask into water.
8. Digest in autoclave for 1 h.

9. Allow samples to cool without mixing, and carefully remove 20.0 ml of supernatent with a 10 ml autopipett (do not disturb sediments at bottom of flask!!).

10. Adjust pH, add 2.0 ml color reagent and proceed with spectrophotometric analysis.

11. Calculate µg P (g dry weight)$^{-1}$ of sediment using this equation:

$$\mu g\ P\ g^{-1} = \frac{(A \times 20 \times 30.97)}{(B \times 20)}$$

where A is the value from standard curve for 50 ml sample (in µMoles).

where B is the dry weight (g) of sediment digested.

12. Triplicate selected samples for statistical analysis.

ANALYSIS OF MOISTURE, INORGANIC, AND ORGANIC CONTENT OF SEDIMENT

1. Place 30 to 40 mls (=cm^3) of unacidified wet sediment into tared crucible and obtain wet weight (expressed as (g wet sediment) cm^{-3}).*

2. Dry sample at 101· C for 24 h and obtain dry weight (expressed as (g dry sediment) cm^{-3}).

3. Ash at 550^{o} C for 2 h and obtain ash weight.

4. Calculate percent moisture, inorganic, and organic content per unit volume of sediment.

*Note: Observe and record sediment texture and type at this point.

APPENDIX II

TRIBUTARY MONITORING

Fig. 1. Temporal variation of turbidity in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

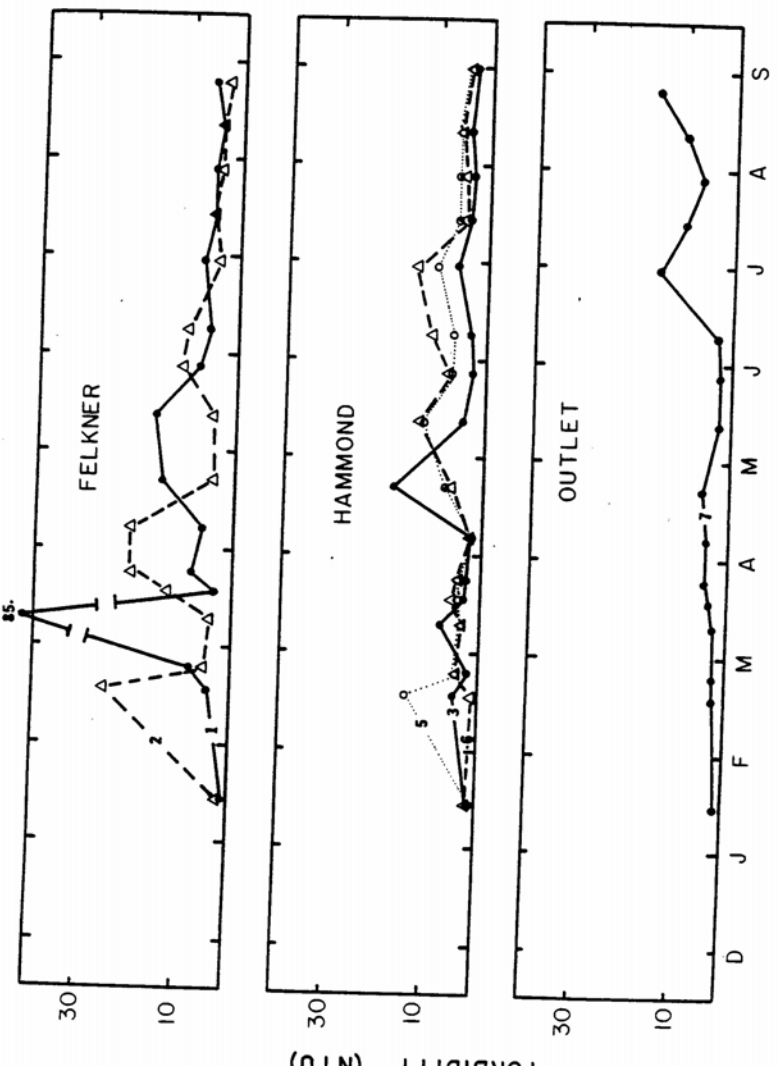

FELKNER
HAMMOND
OUTLET
TURBIDITY (NTU)
30
10
85.
D
J
F
M
A
M
J
J
A
S
1981

Fig. 2. Temporal variation of total phosphorus in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

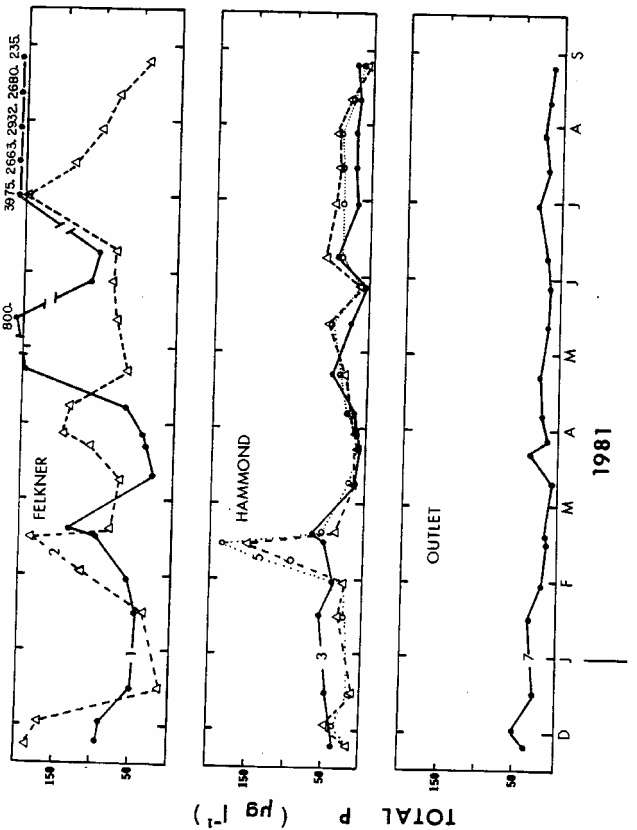

FELKNER
HAMMOND
OUTLET
800.
3975. 2663. 2932. 2680. 235.
150
50
D
J
F
M
A
M
J
J
A
S
1981
TOTAL P (µg l⁻¹)

Fig. 3. Temporal variation of soluble reactive phosphorus in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

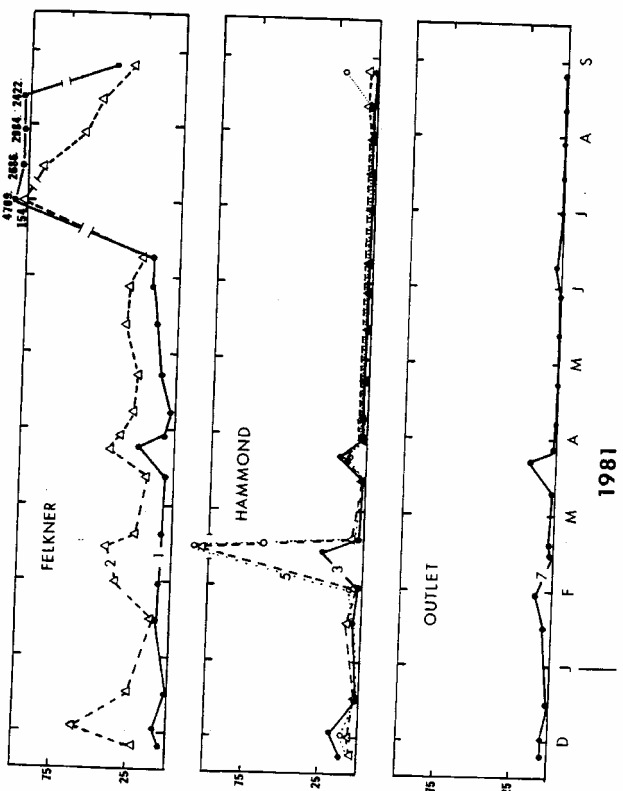

FELKNER
HAMMOND
OUTLET
ORTHO P (µg l⁻¹)
75
25
D
J
F
M
A
M
J
J
A
S
1981

Fig. 4. Temporal variation of ammonia in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

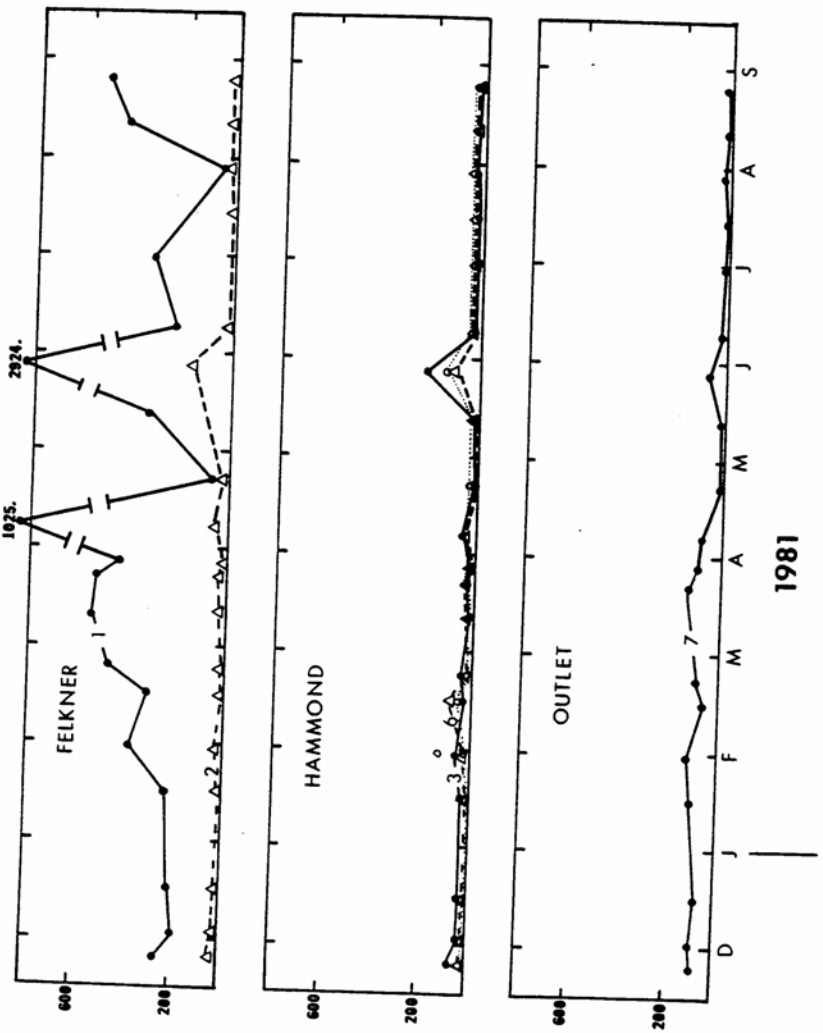

FELKNER
HAMMOND
OUTLET
1825.
2824.
600
200
D
J
F
M
A
M
J
J
A
S
1981
AMMONIA (µg l⁻¹)

Fig. 5. Temporal variation of nitrite in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

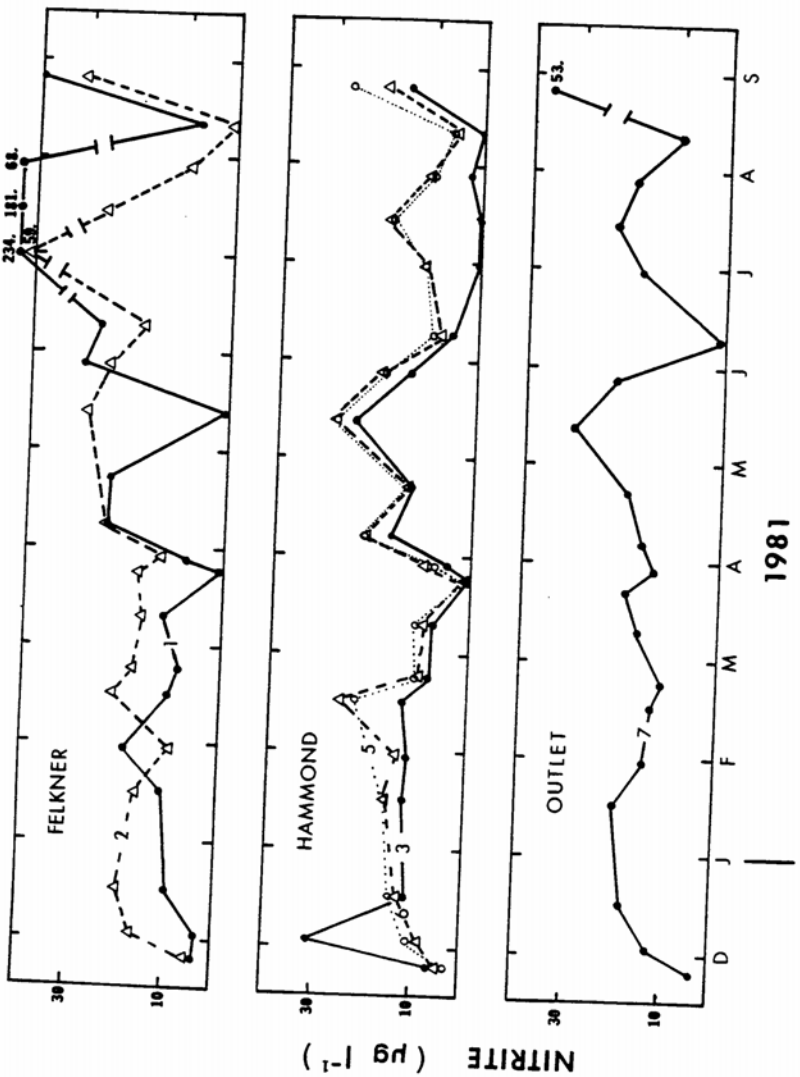

FELKNER
HAMMOND
OUTLET
234.
181.
68.
53.
30
10
D
J
F
M
A
M
J
J
A
S
1981
NITRITE (µg l⁻¹)

Fig. 6. Temporal variation of nitrate in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

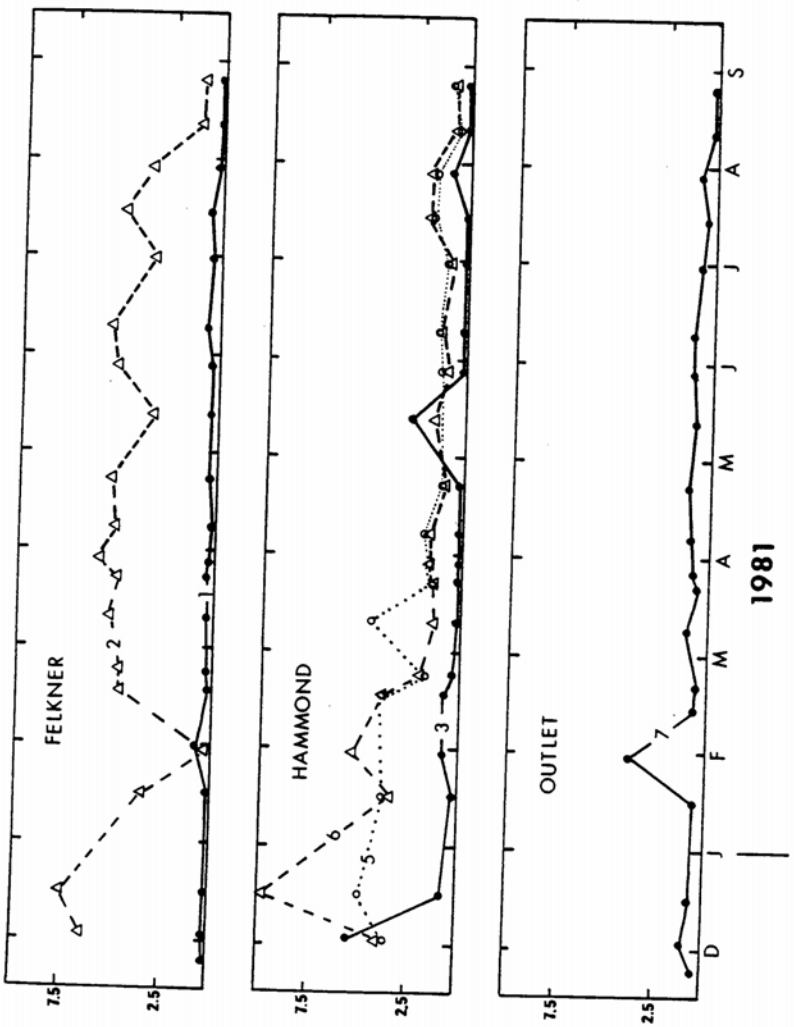

FELKNER
HAMMOND
OUTLET
7.5
2.5
D
J
F
M
A
M
J
J
A
S
1981
NITRATE (mg l⁻¹)

Fig. 7. Temporal variation of organic nitrogen in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

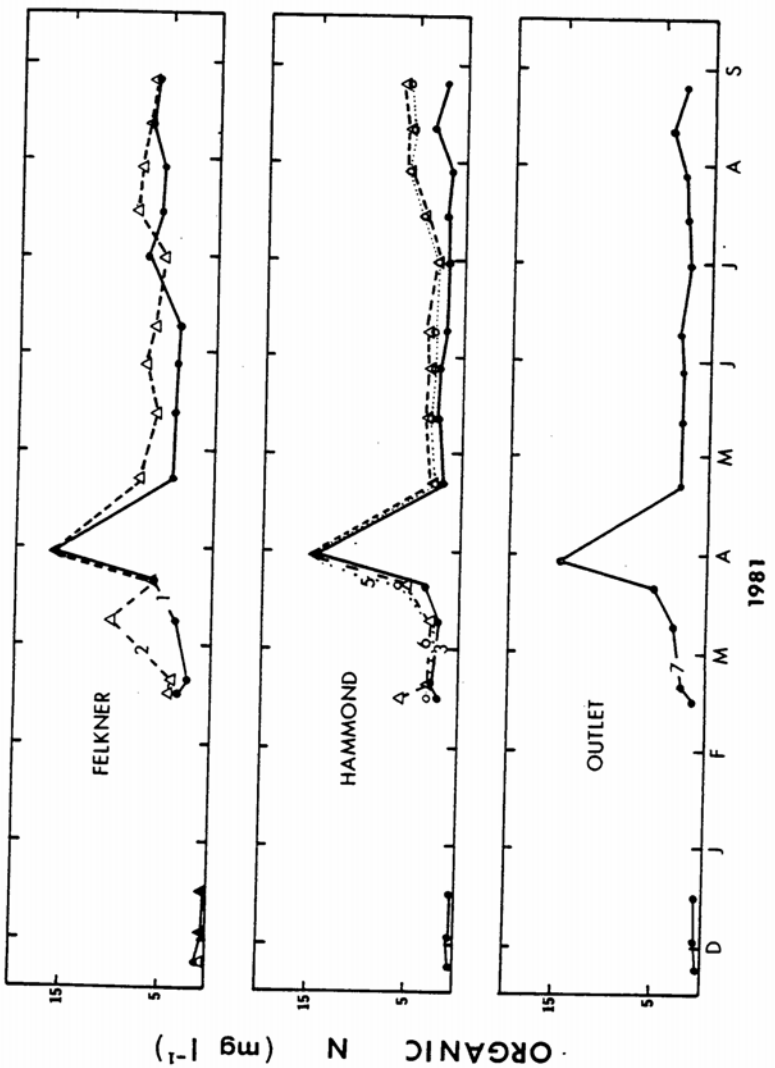

FELKNER
HAMMOND
OUTLET
15
5
D
J
F
M
A
M
J
J
A
S
1981
ORGANIC N (mg l⁻¹)

Fig. 8. Temporal variation of silica in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

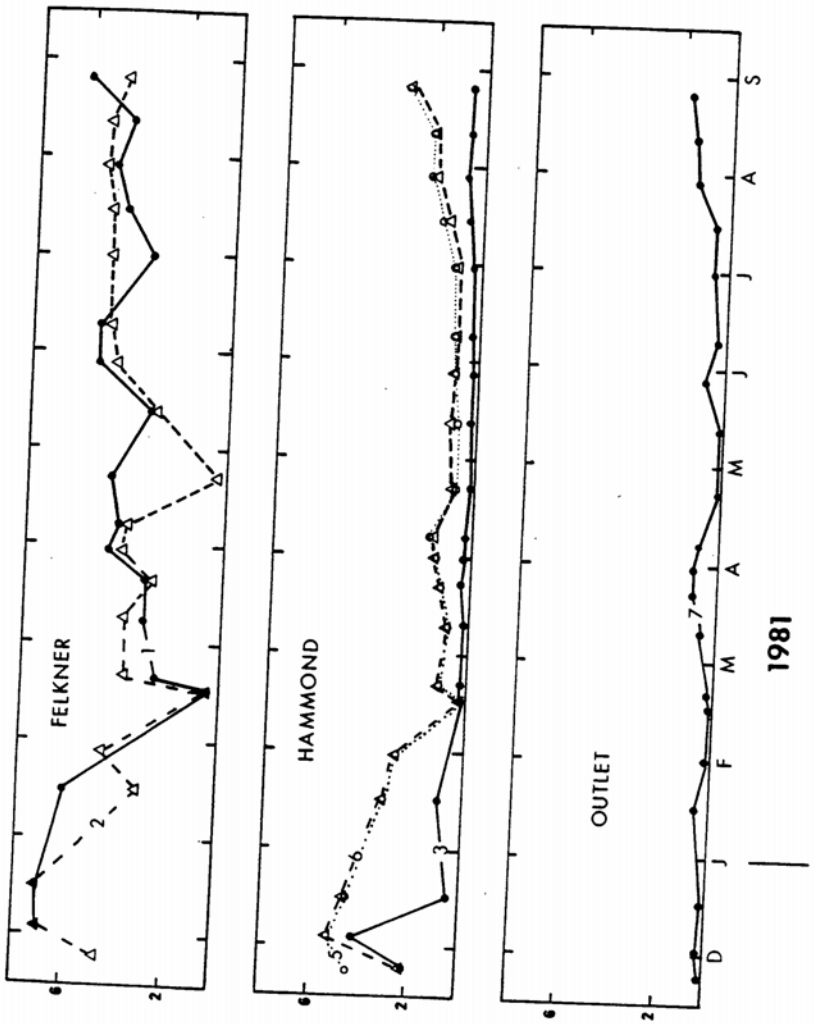

FELKNER
HAMMOND
OUTLET
SILICA (mg l⁻¹)
D
J
F
M
A
M
J
J
A
S
1981

Fig. 9. Temporal variation of total residue in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

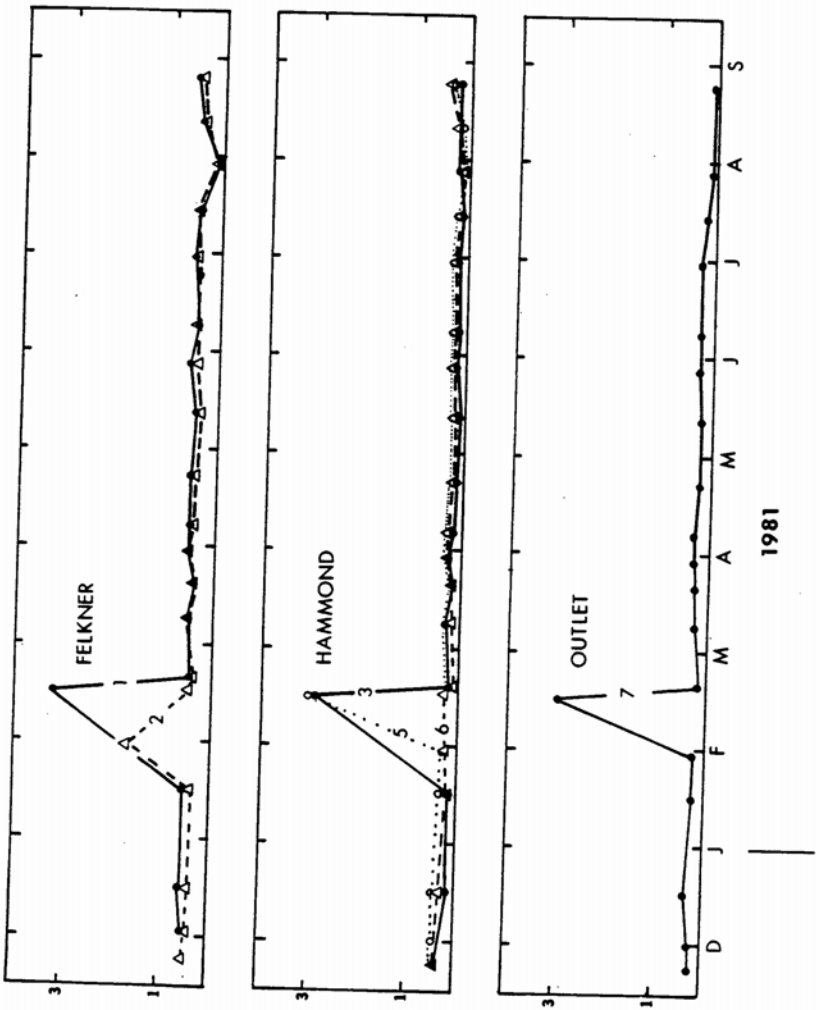

FELKNER
HAMMOND
OUTLET
TOTAL RESIDUE (g l⁻¹)
3
1
D
J
F
M
A
M
J
J
A
S
1981

Fig. 10. Temporal variation of organic residue in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

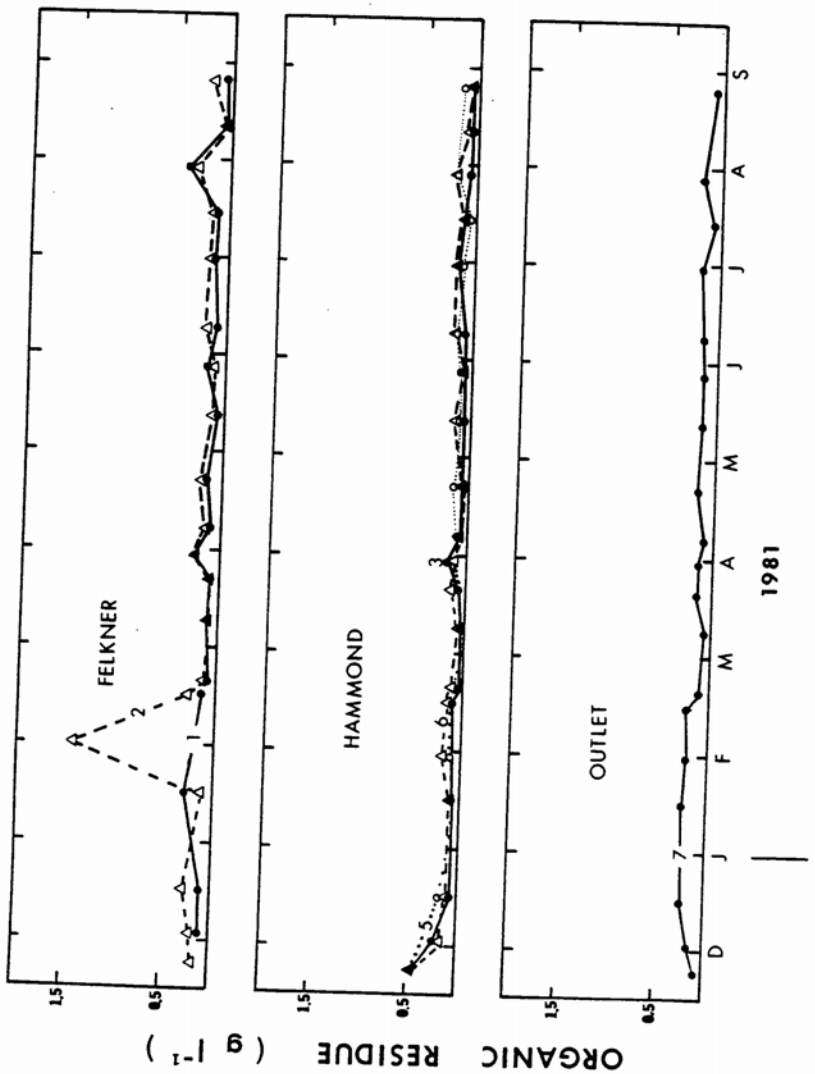

ORGANIC RESIDUE (g l⁻¹)
FELKNER
HAMMOND
OUTLET
1.5
0.5
D
J
F
M
A
M
J
J
A
S
1981

Fig. 11. Temporal variation of total particulate matter in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

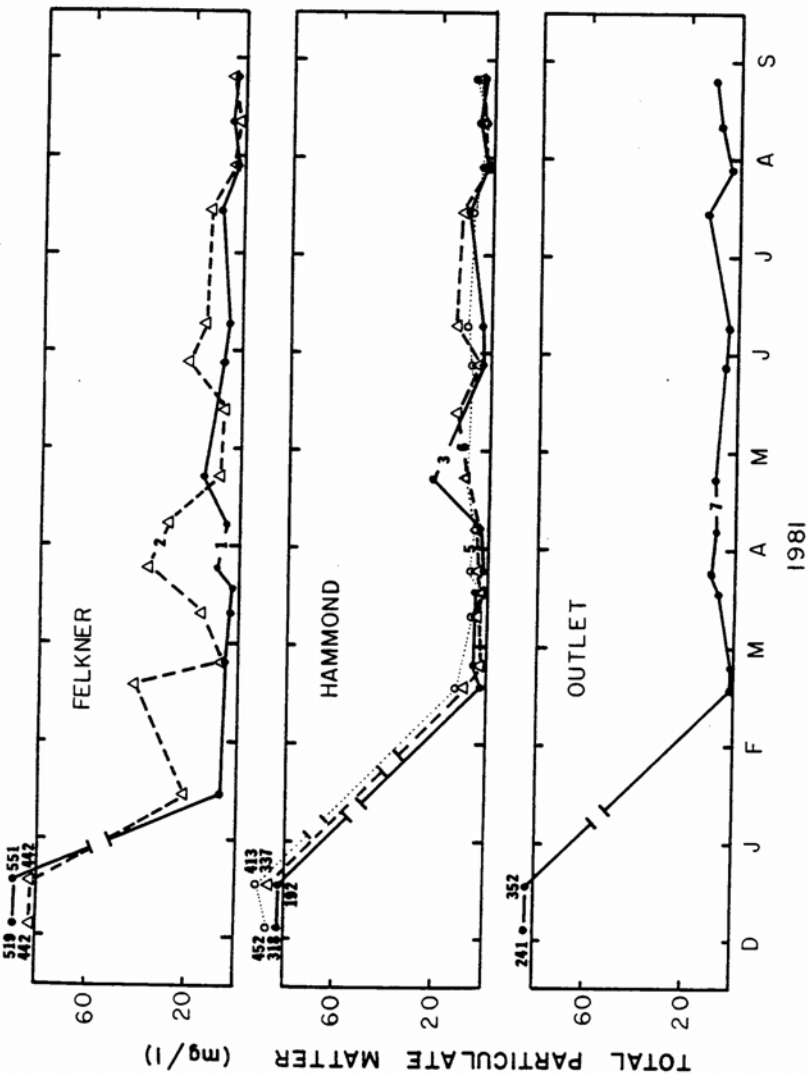

FELKNER
HAMMOND
OUTLET
TOTAL PARTICULATE MATTER (mg/l)
60
20
519
442
551
442
452
318
413
337
182
241
352
D
J
F
M
A
M
J
J
A
S
1981

Fig. 12. Temporal variation of particulate organic matter in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.

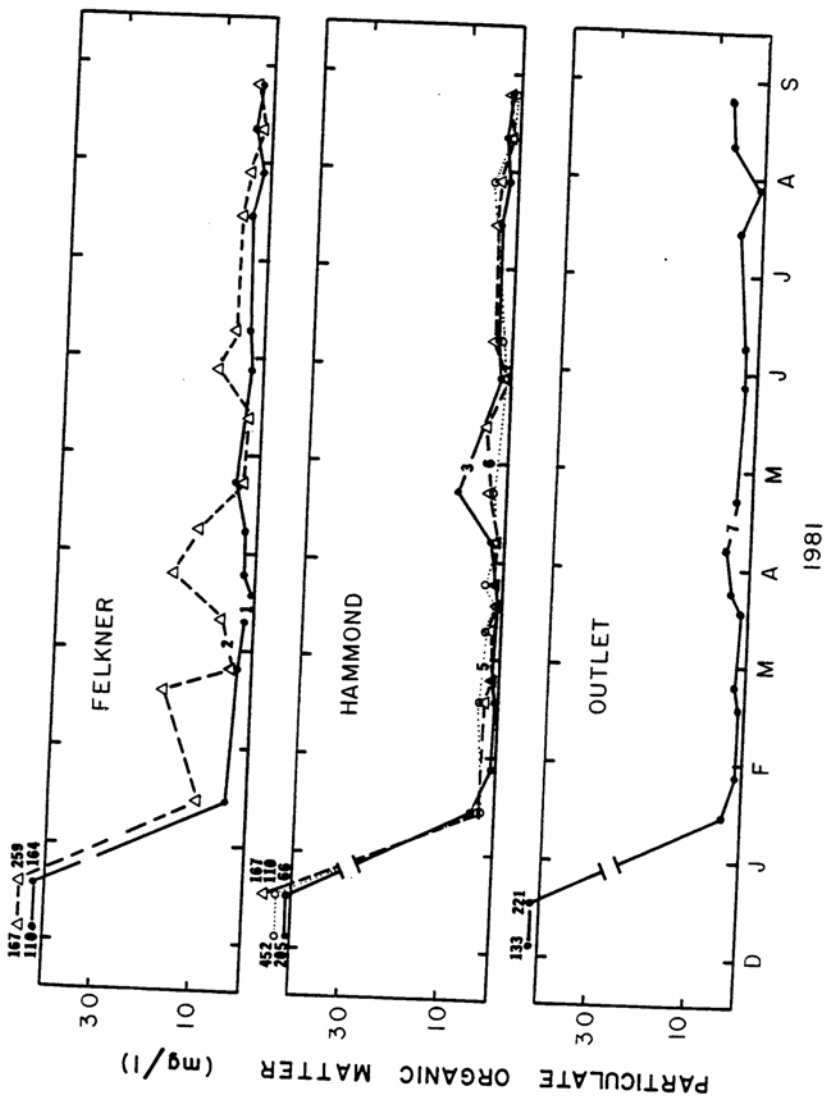
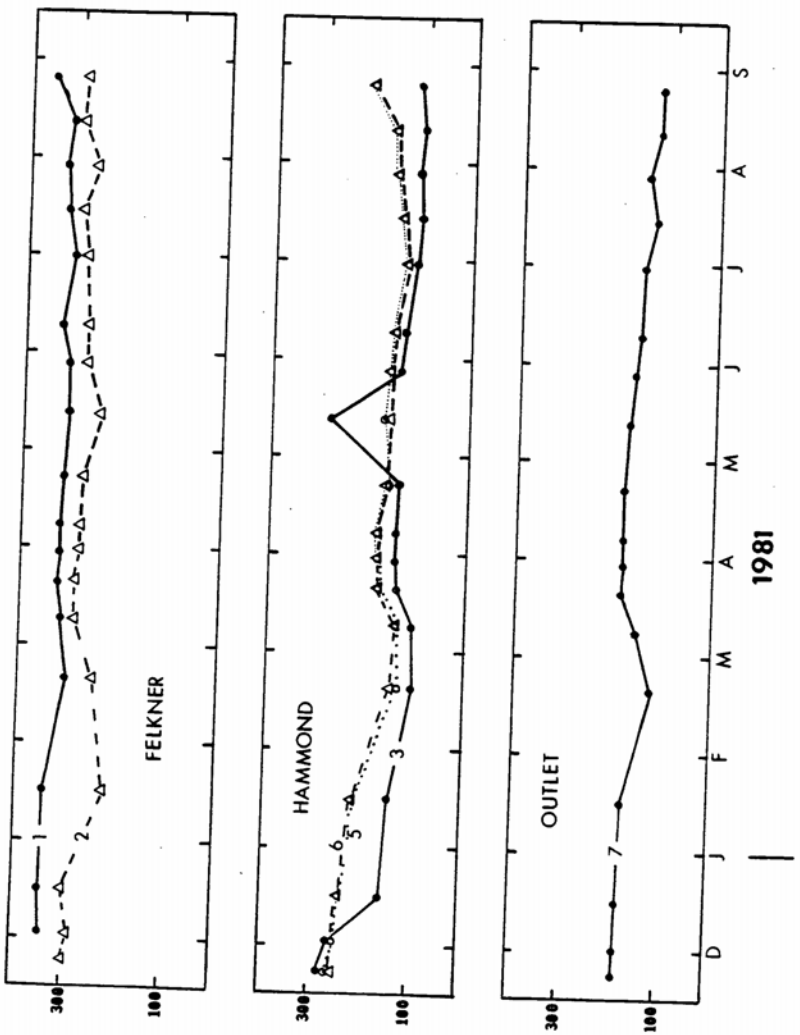

FELKNER
HAMMOND
OUTLET
PARTICULATE ORGANIC MATTER (mg/l)
30
10
D
J
F
M
A
M
J
J
A
S
1981

Fig. 13. Temopral variation of total alkalinity in the tributaries and Outlet of Lake Waubee. Numbers denote sampling sites.


TOTAL ALKALINITY (mg l⁻¹)
FELKNER
HAMMOND
OUTLET
300
100
1
2
3
5
7
D
J
F
M
A
M
J
J
A
S
1981

APPENDIX III

LAKE MONITORING

APPENDIX III (con't.)

APPENDIX III (con't.)

Fig. 1a-d. Temporal variation in temperature profiles at the deep and shallow stations of Lake Waubee.

Fig. 1a.

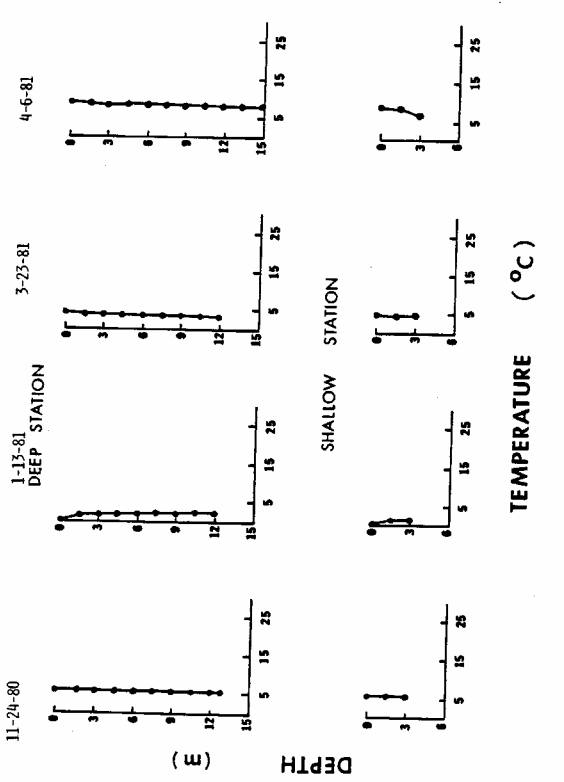

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH
(m)
TEMPERATURE (°C)

Fig. 1b.

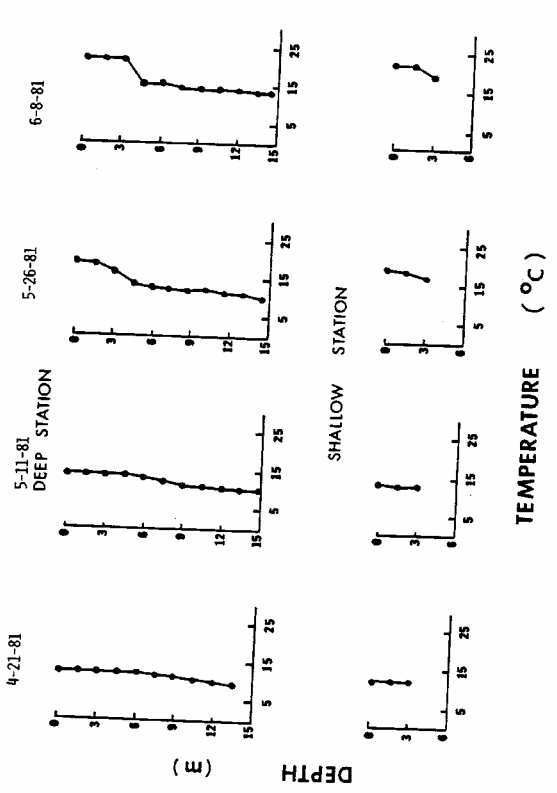

4-21-81
5-11-81
DEEP STATION
5-26-81
6-8-81
SHALLOW STATION
DEPTH
(m)
TEMPERATURE (°C)

Fig. 1c.

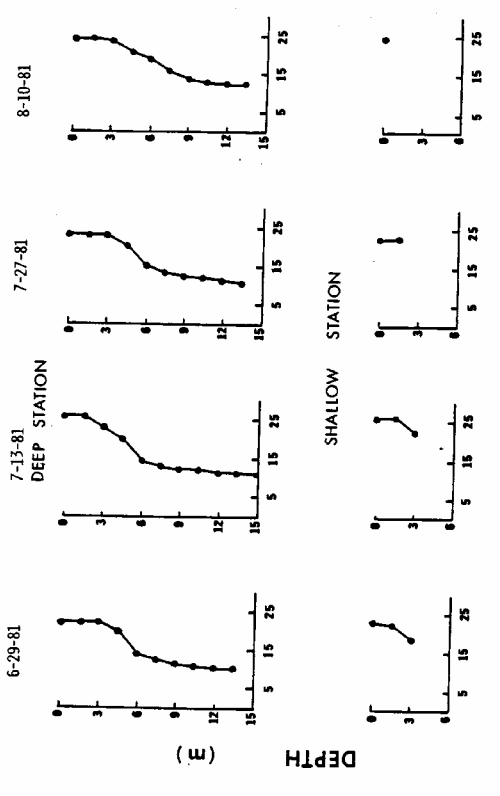

6-29-81
7-13-81
DEEP STATION
7-27-81
8-10-81
SHALLOW STATION
DEPTH (m)
TEMPERATURE (°C)
0
3
6
9
12
15
5
15
25

Fig. 1d.

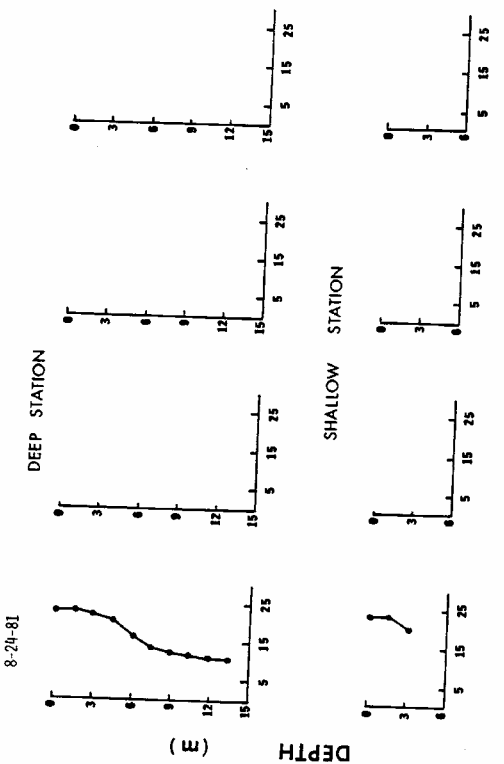


Fig. 2a–e. Temporal variation in conductivity profiles at the deep and shallow stations of Lake Waubee.

Fig. 2a.

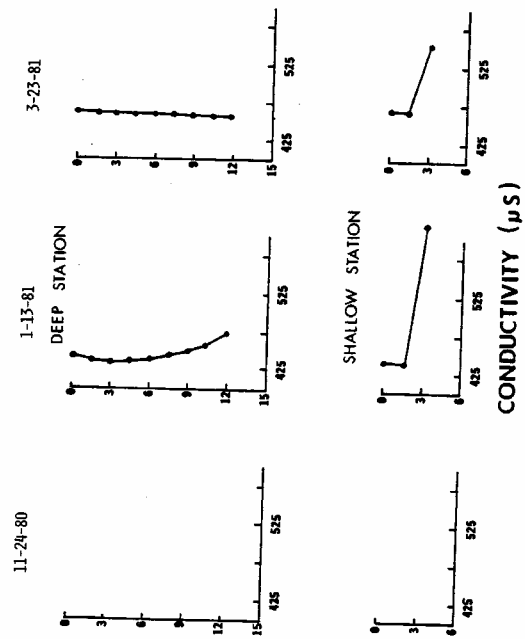

11-24-80
1-13-81
DEEP STATION
3-23-81
SHALLOW STATION
DEPTH (m)
CONDUCTIVITY (μS)
0
3
6
9
12
15
425
525

Fig. 2b.

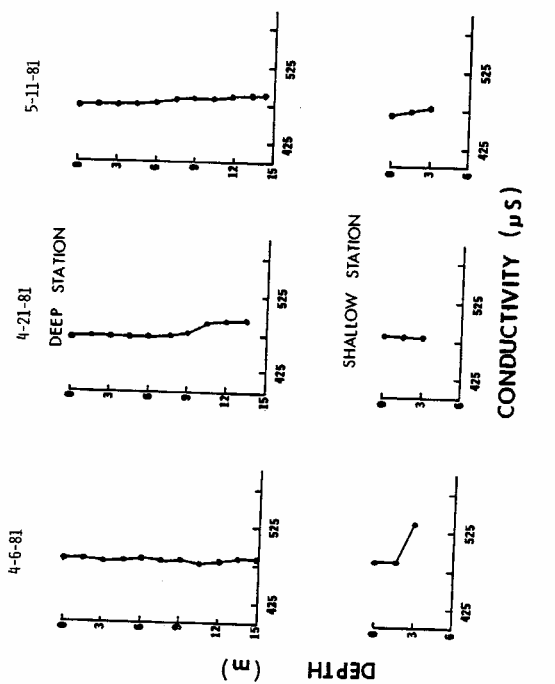

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
CONDUCTIVITY (μS)
0
3
6
9
12
15
425
525

Fig. 2c.

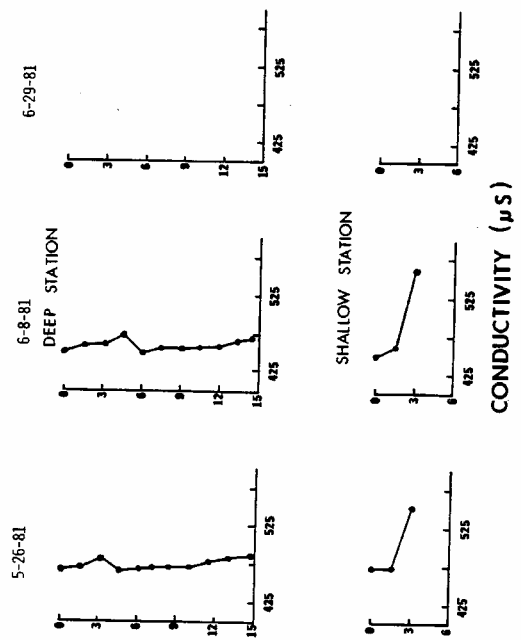

5-26-81
6-8-81
DEEP STATION
6-29-81
SHALLOW STATION
DEPTH (m)
CONDUCTIVITY (μS)
0
3
6
9
12
15
425
525

Fig. 2d.

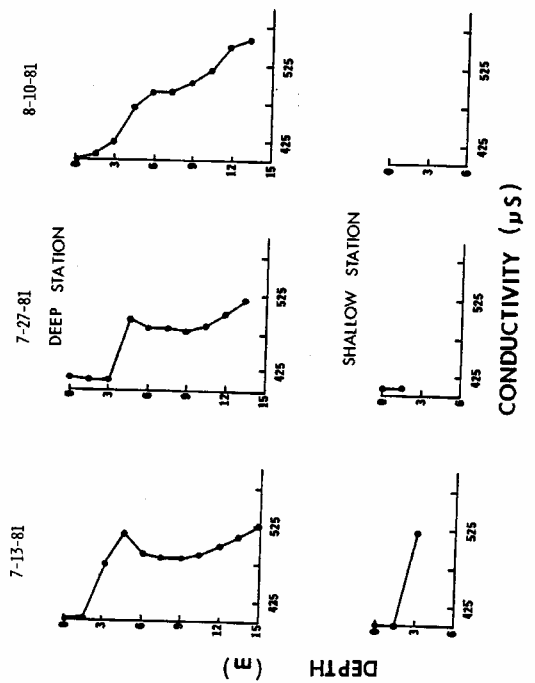

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
0
3
6
9
12
15
425
525
CONDUCTIVITY (μS)

Fig. 2e.

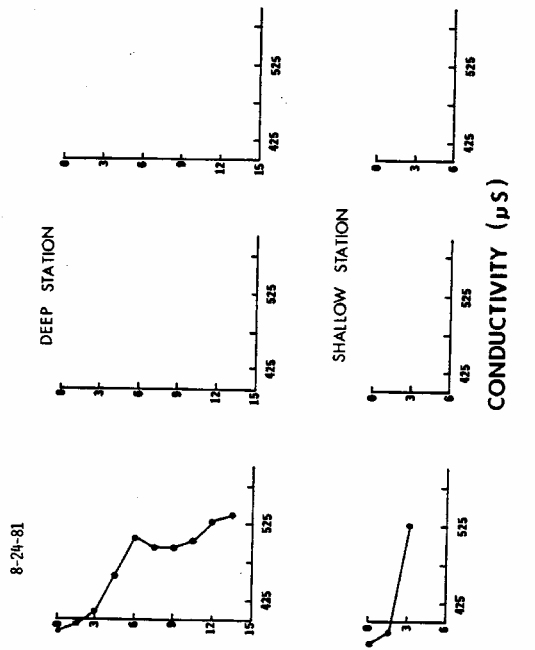

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
CONDUCTIVITY (μS)
0
3
6
9
12
15
425
525

Fig. 3a-d. Temporal variation in turbidity profiles at the deep and shallow stations of Lake Waubee.

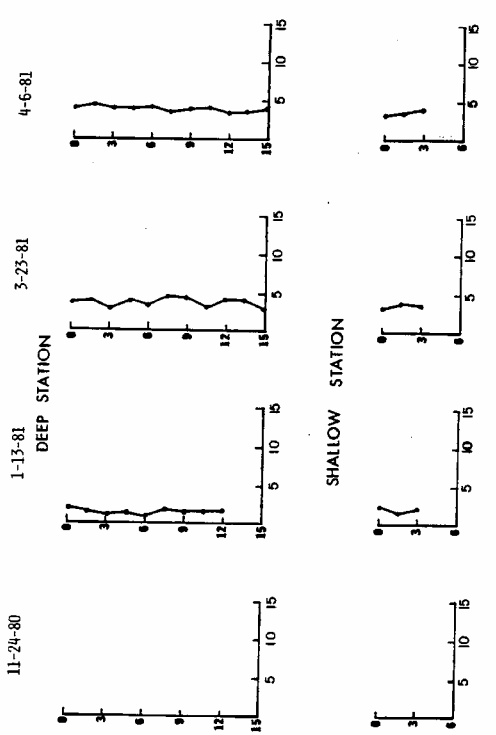
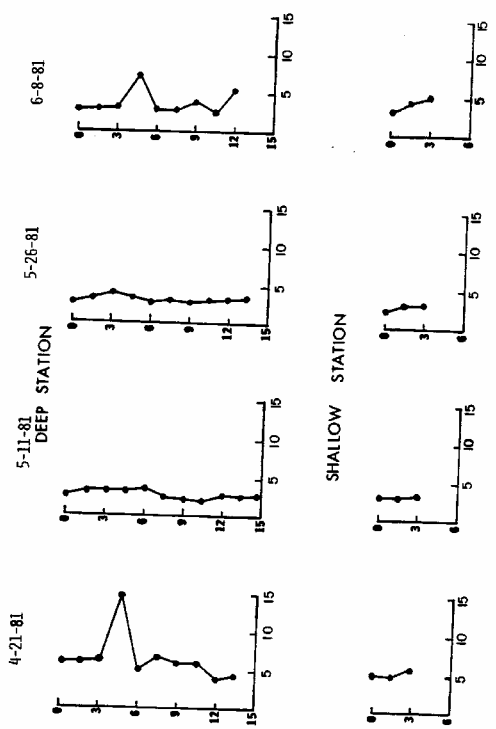

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TURBIDITY (NTU)

Fig. 3b.


4-21-81
5-11-81
5-26-81
6-8-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TURBIDITIY (NTU)

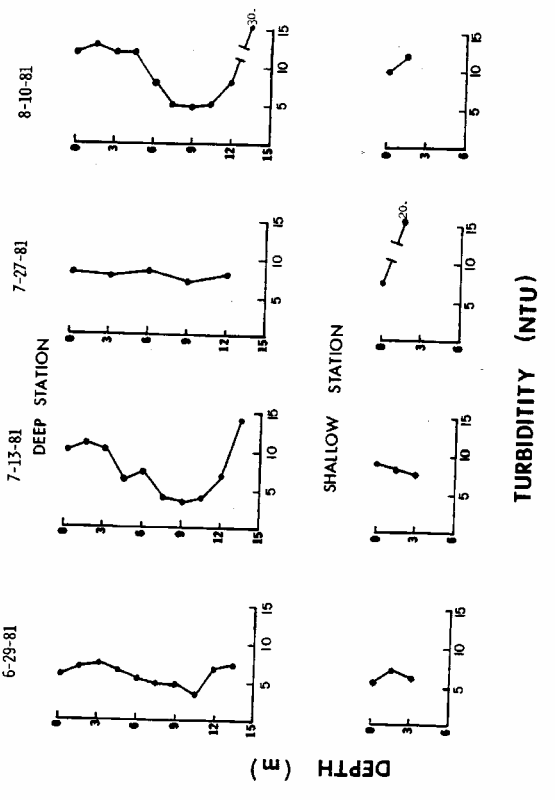

6-29-81
7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TURBIDITY (NTU)
0
3
6
9
12
15
5
10
15
20.
30.

Fig. 3d.

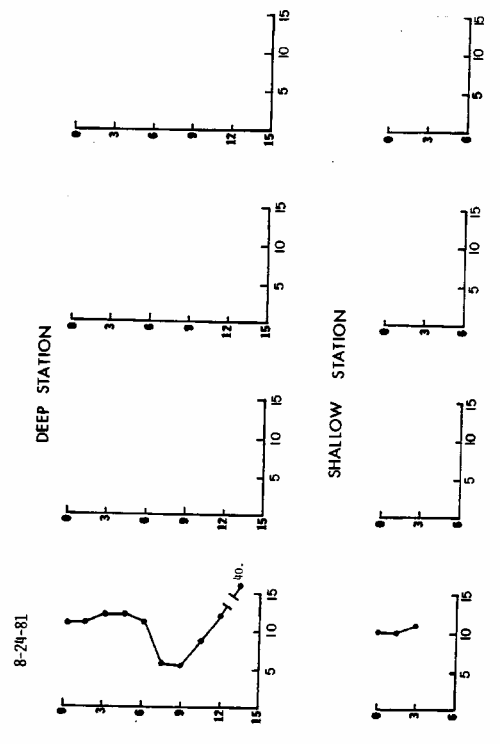

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TURBIDITITY (NTU)
0
3
6
9
12
15
5
10
15
40

Fig. 4. Temporal variation in Secchi depth at the deep (●) and shallow (△) stations of Lake Waubee.

Fig. 4.

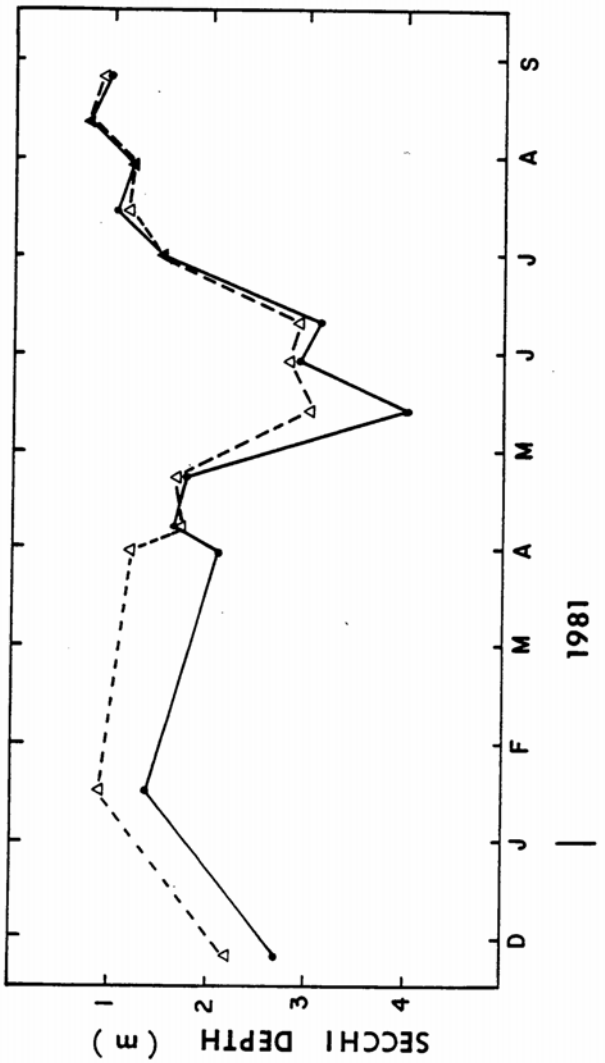


Fig. 5a-d. Temporal variation in pH profiles at the deep and shallow stations of Lake Waubee.

Fig. 5a.

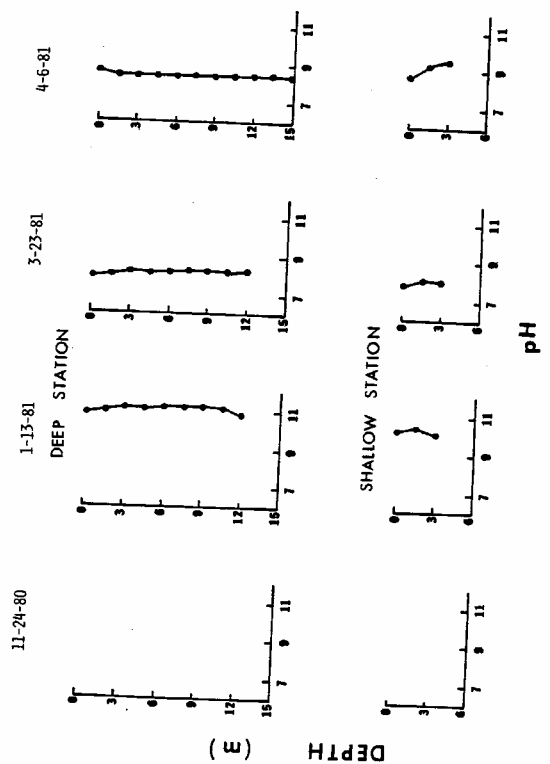

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
pH

Fig. 5b.

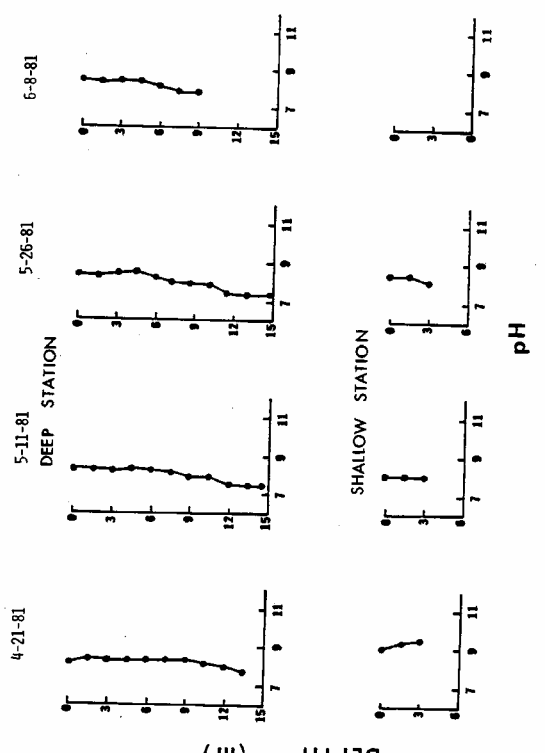

4-21-81
5-11-81
5-26-81
6-8-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
pH

Fig. 5c.

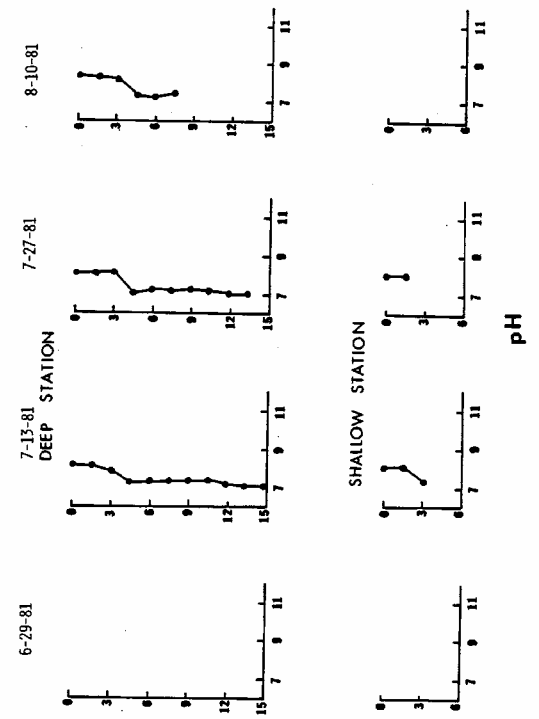

6-29-81
7-13-81
DEEP STATION
7-27-81
8-10-81
SHALLOW STATION
DEPTH (m)
pH

Fig. 5d.

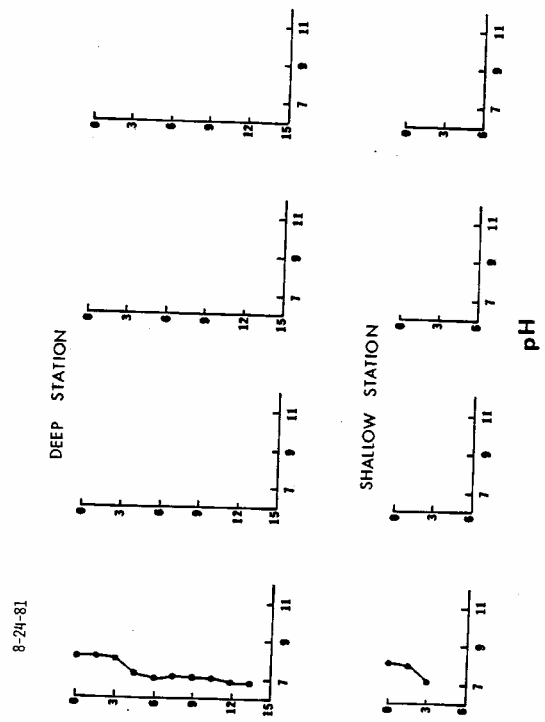


Fig. 6a-d. Temporal variation in dissolved oxygen profiles at the deep and shallow stations of Lake Waubee.

Fig. 6a.

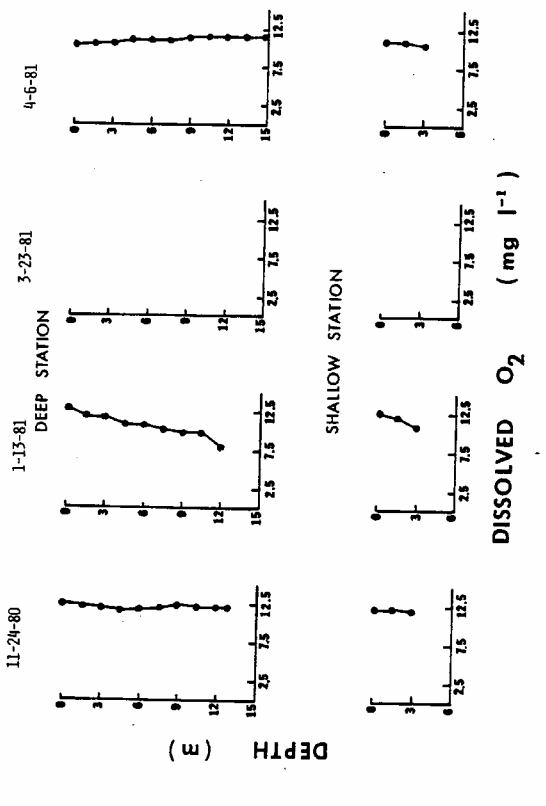

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
DISSOLVED O_2 (mg l^{-1})
0
3
6
9
12
15
2.5
7.5
12.5

Fig. 6b.

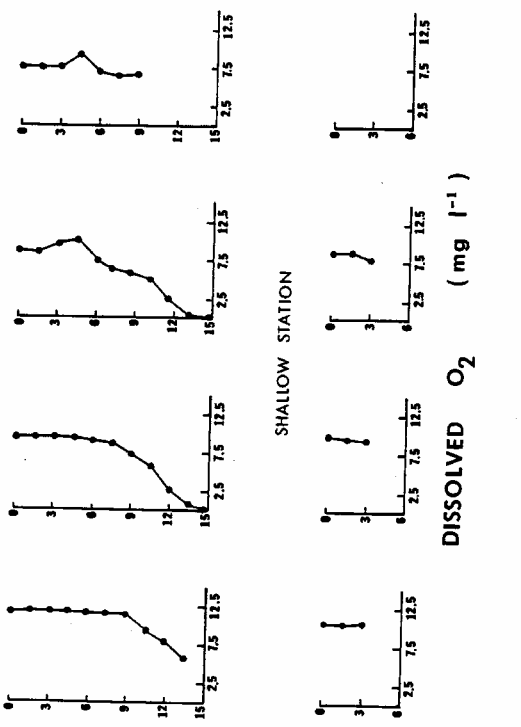

4-21-81
5-11-81
5-26-81
6-8-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
DISSOLVED O2 (mg l-1)
0
3
6
9
12
15
2.5
7.5
12.5

Fig. 6c.

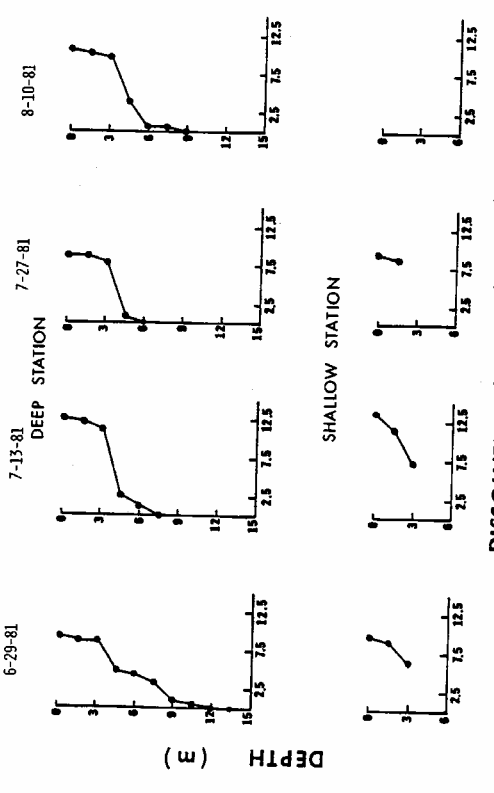

6-29-81
7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
DISSOLVED O_2 (mg l^{-1})
0
3
6
9
12
15
2.5
5.0
7.5
10.0
12.5

Fig. 6d.

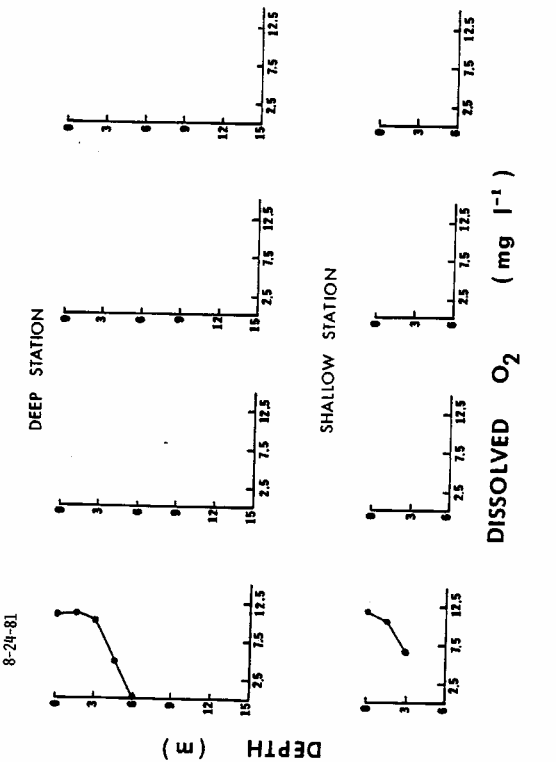

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
DISSOLVED O_2 (mg l^{-1})
0
3
6
9
12
15
2.5
7.5
12.5

Fig. 7a-d. Temporal variation in total phosphorus profiles at the deep and shallow stations of Lake Waubee.

Fig. 7a.

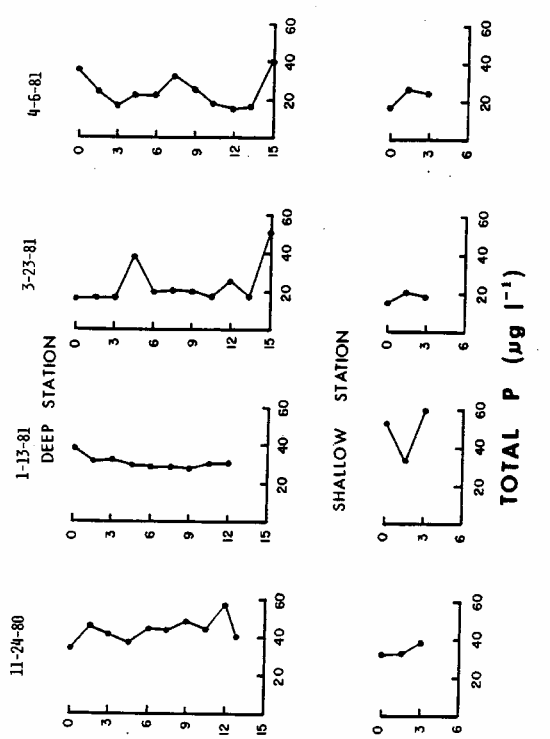

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL P (µg l⁻¹)

Fig. 7b.

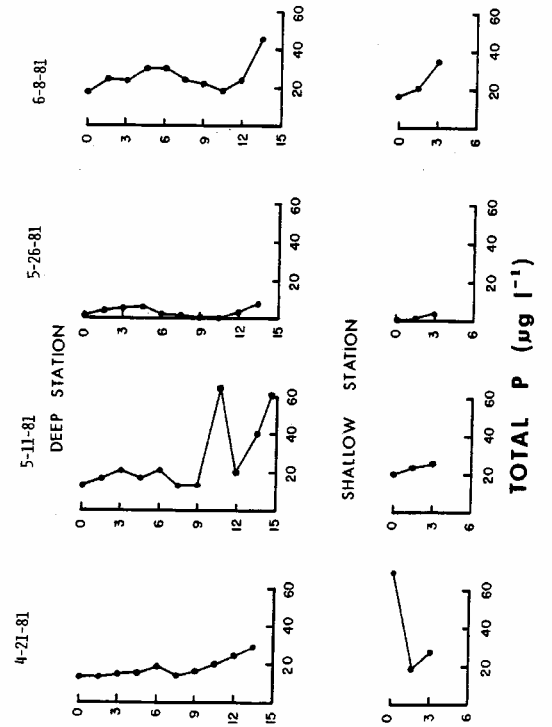

4-21-81
5-11-81
5-26-81
6-8-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL P (µg l⁻¹)

Fig. 7c.

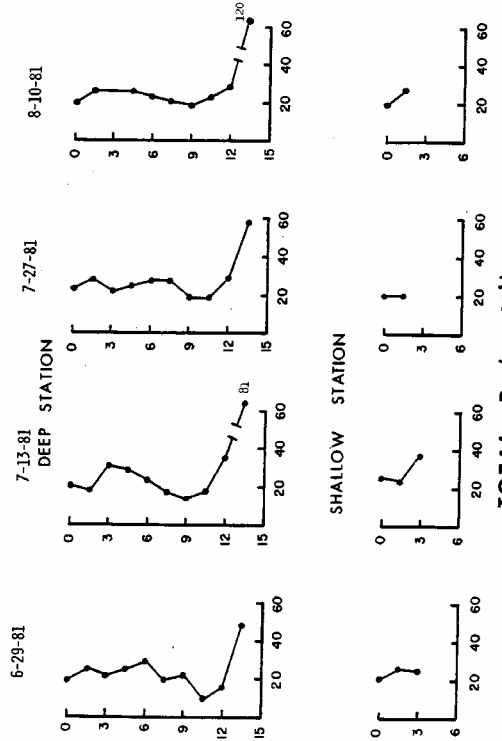

6-29-81
7-13-81
DEEP STATION
7-27-81
8-10-81
SHALLOW STATION
DEPTH (m)
TOTAL P (µg l⁻¹)
81
120

Fig. 7d.

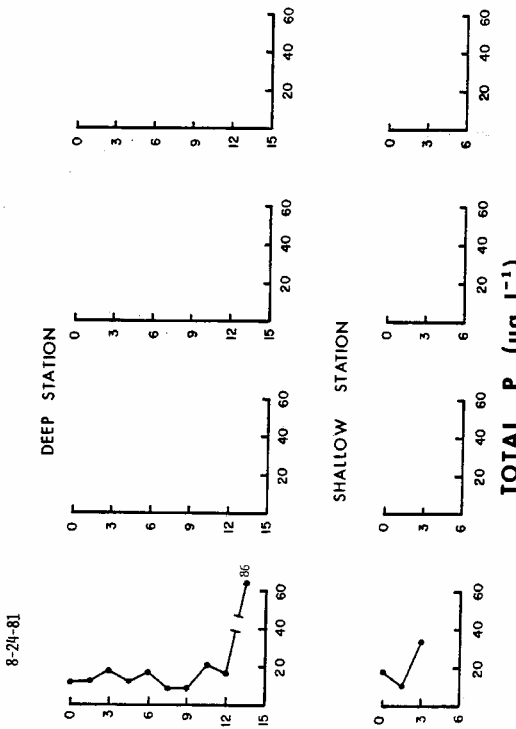

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL P (µg l⁻¹)
0
3
6
9
12
15
20
40
60
86

Fig. 8a-e. Temporal variation in soluble reactive phosphorus profiles at the deep and shallow stations of Lake Waubee.

Fig. 8a.

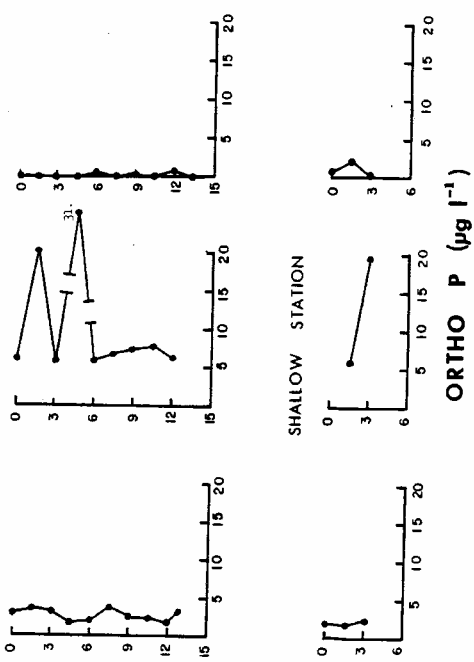

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORTHO P (µg l⁻¹)
31

Fig. 8b.

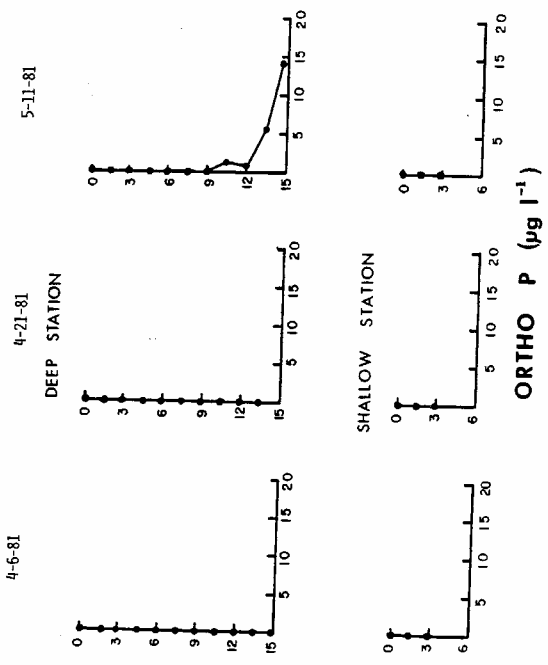

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORTHO P (µg l⁻¹)

Fig. 8c.

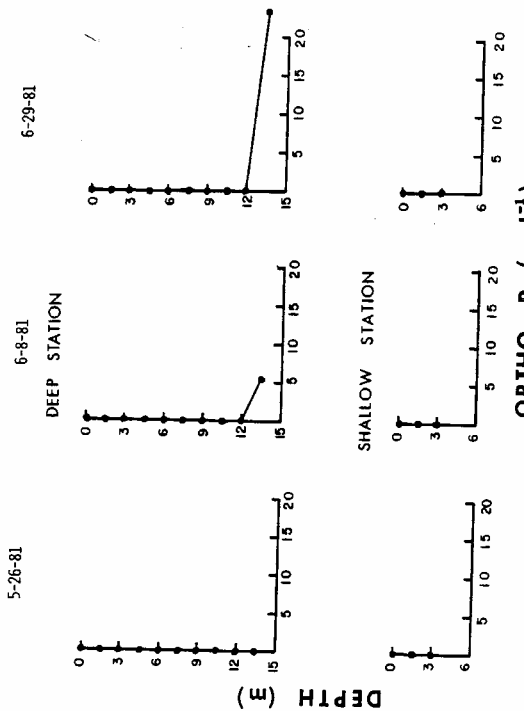

5-26-81
6-8-81
6-29-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORTHO P (µg l⁻¹)

Fig. 8d.

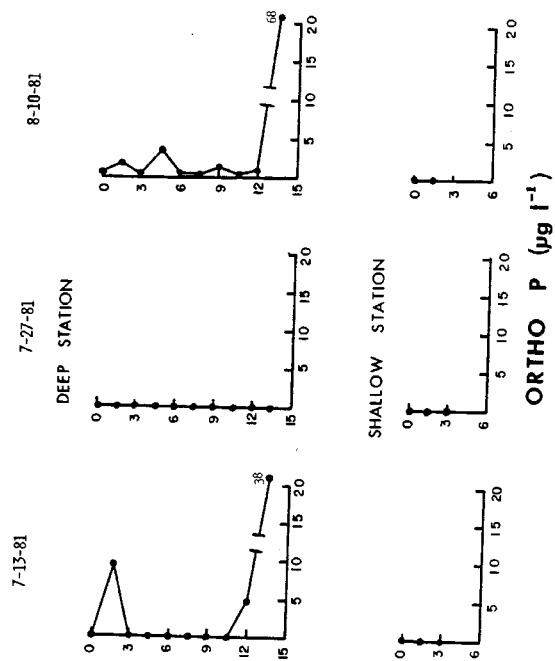

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORTHO P (µg l⁻¹)
0
3
6
9
12
15
5
10
15
20
38
68

Fig. 8e.

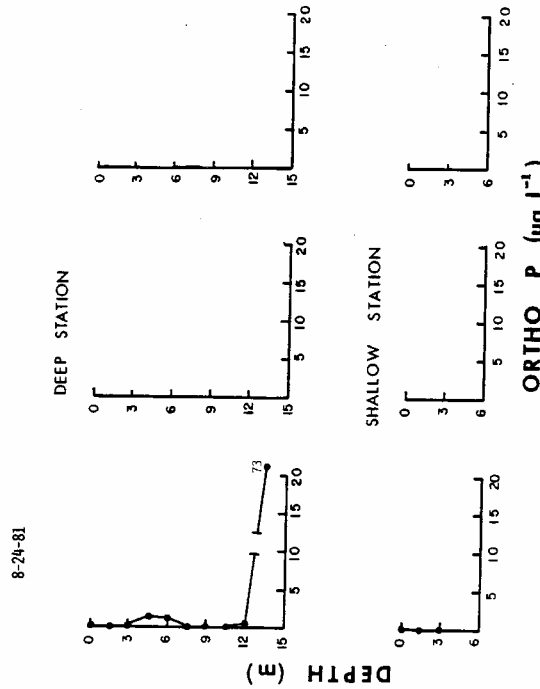


Fig. 9a-e. Temporal variation in ammonia profiles at the deep and shallow stations of Lake Waubee.

Fig. 9a.

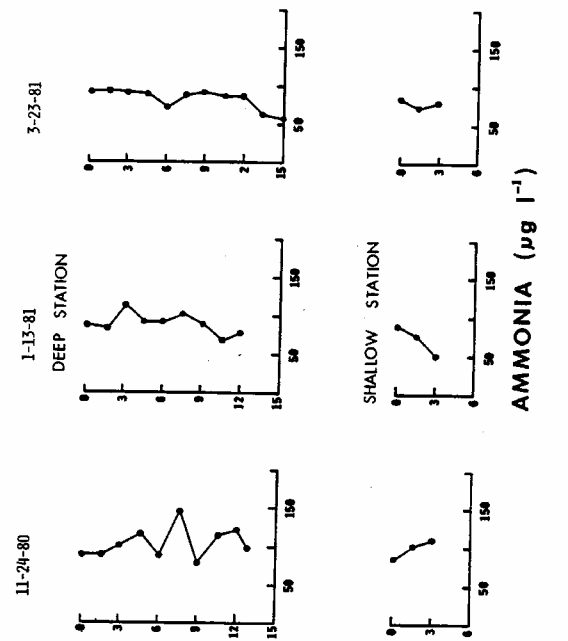

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
AMMONIA (μg l⁻¹)

Fig. 9b.

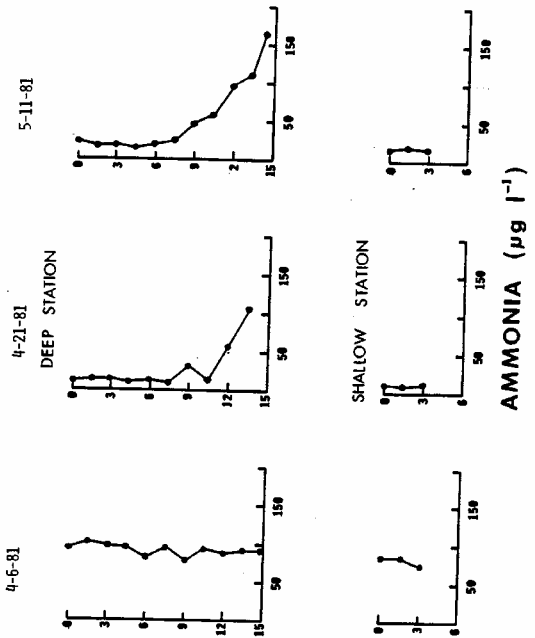

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
AMMONIA (μg l⁻¹)

Fig. 9c.

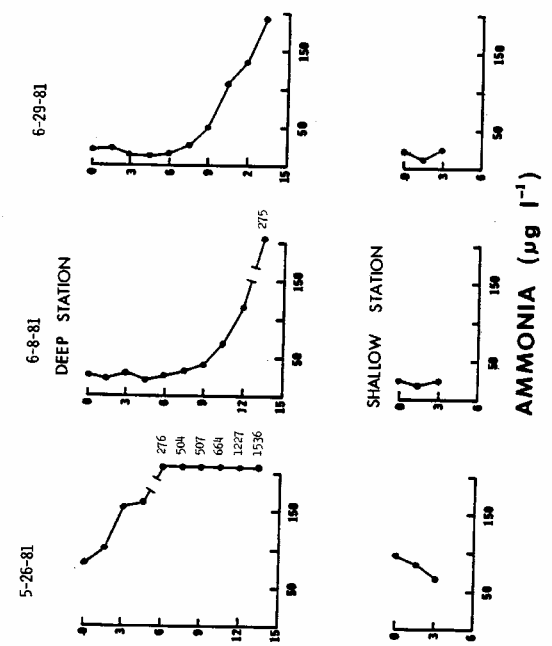

5-26-81
6-8-81
DEEP STATION
6-29-81
SHALLOW STATION
276
504
507
664
1227
1536
275
DEPTH (m)
AMMONIA (µg l⁻¹)

Fig. 9d.

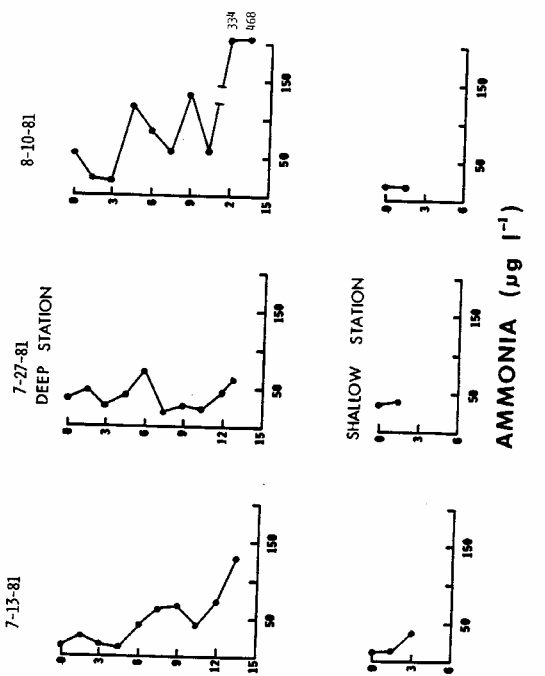

7-13-81
7-27-81
DEEP STATION
8-10-81
SHALLOW STATION
DEPTH (m)
AMMONIA (μg l⁻¹)
0
3
6
9
12
15
50
150
2
334
468

Fig. 9e.

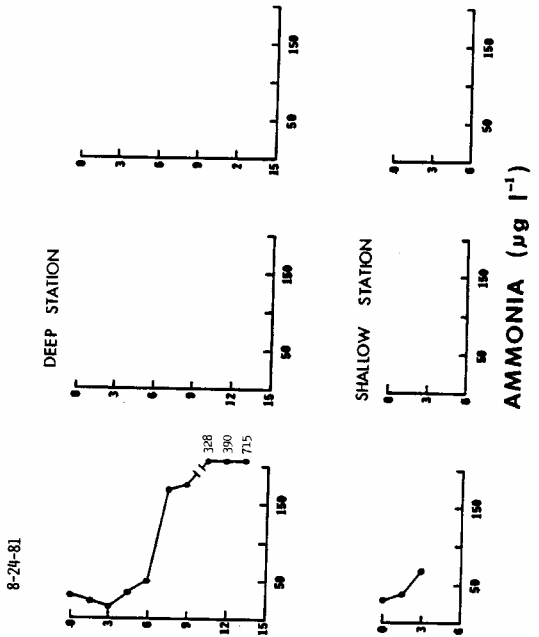

8-24-81
DEEP STATION
SHALLOW STATION
328
390
715
DEPTH (m)
AMMONIA (μg l⁻¹)

Fig. 10a-d. Temporal variation in nitrite profiles at the deep and shallow stations of Lake Waubee.

Fig. 10a.

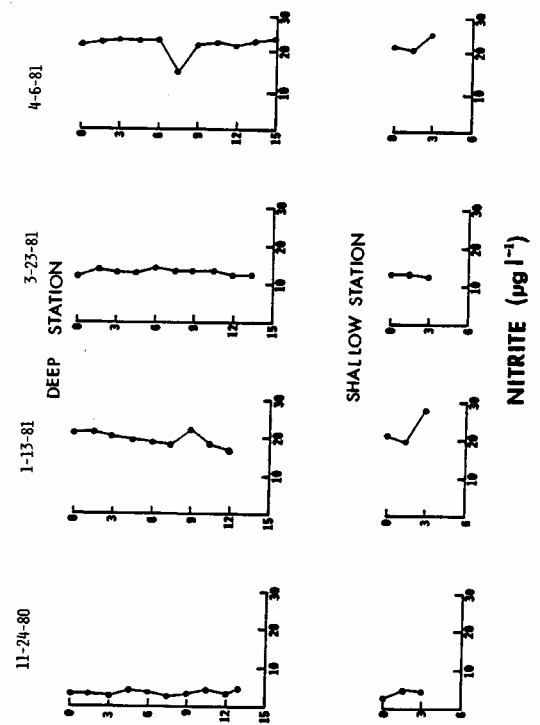

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRITE (μg l⁻¹)

Fig. 10b.

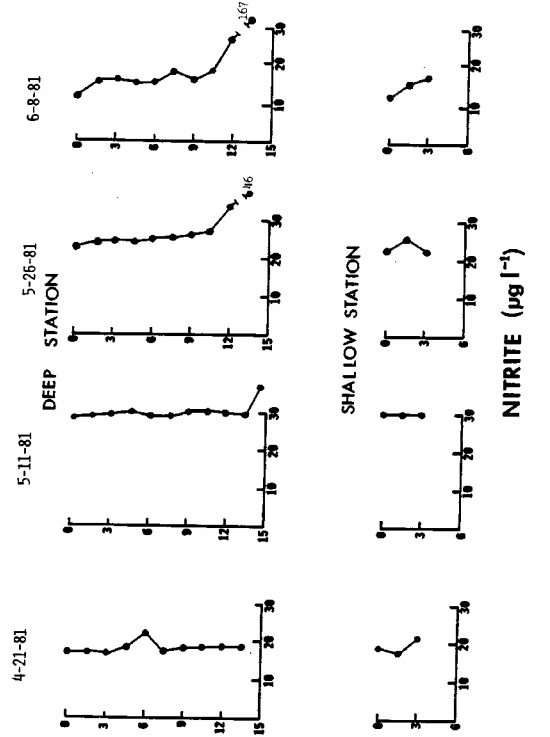

4-21-81
5-11-81
5-26-81
6-8-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRITE (μg l⁻¹)
0
3
6
9
12
15
10
20
30
46
167

Fig. 10c.

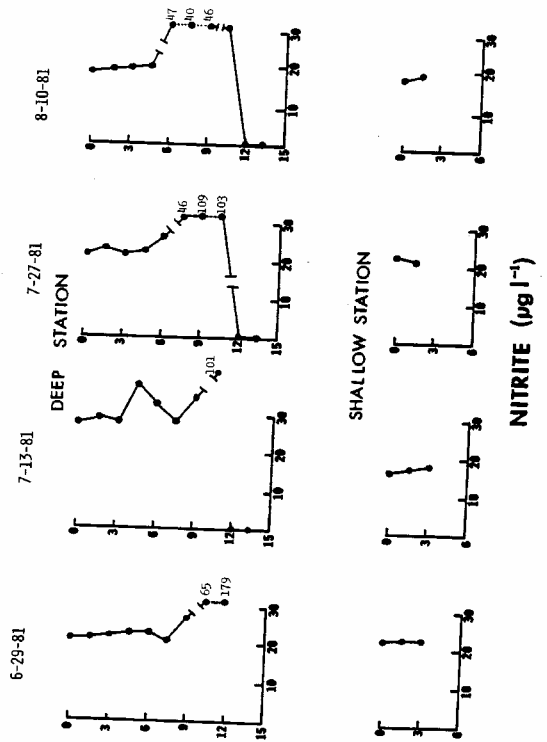

6-29-81
7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRITE (μg l⁻¹)

Fig. 10d.

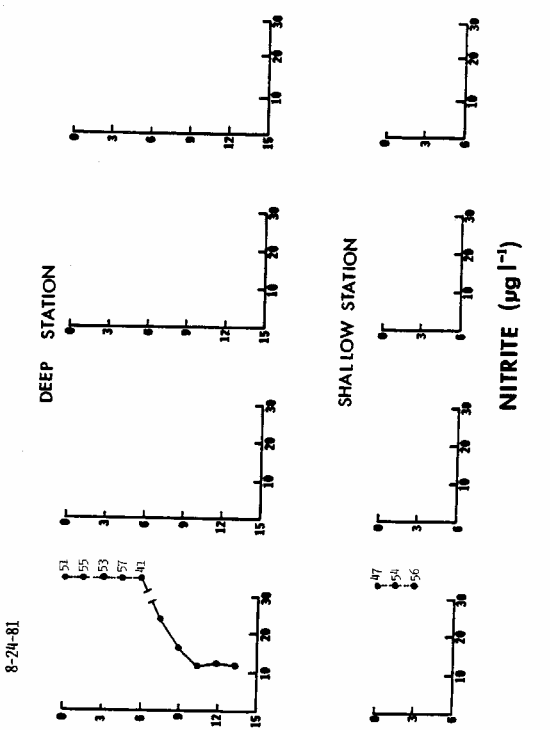


Fig. 11a-e. Temporal variation in nitrate profiles at the deep and shallow stations of Lake Waubee.

Fig. 11a.

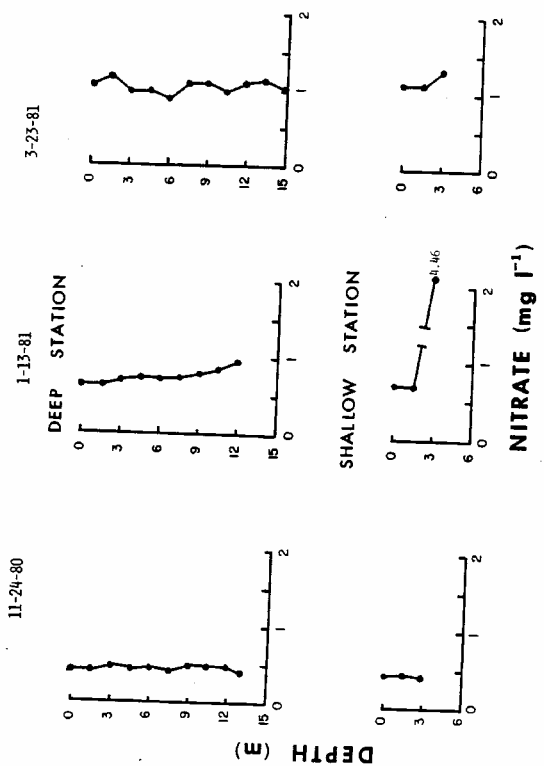

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRATE (mg l⁻¹)
0
3
6
9
12
15
1
2
1.46

Fig. 11b.

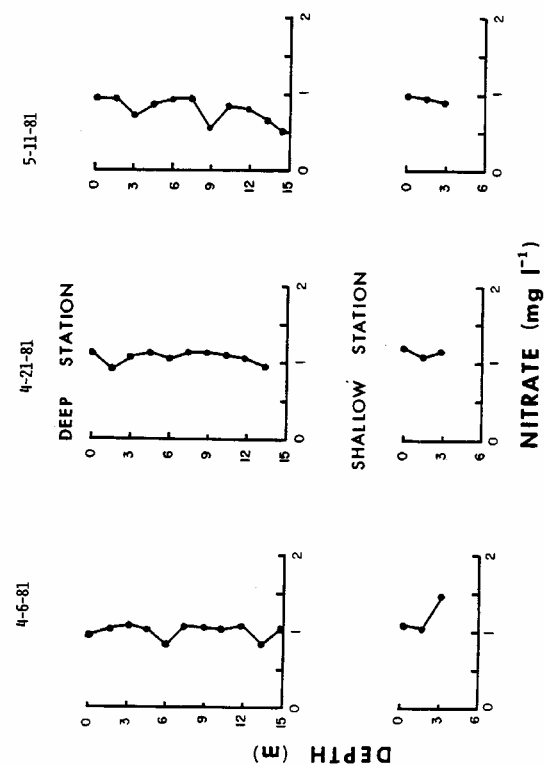

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRATE (mg l⁻¹)
0
3
6
9
12
15
1
2

Fig. 11c.

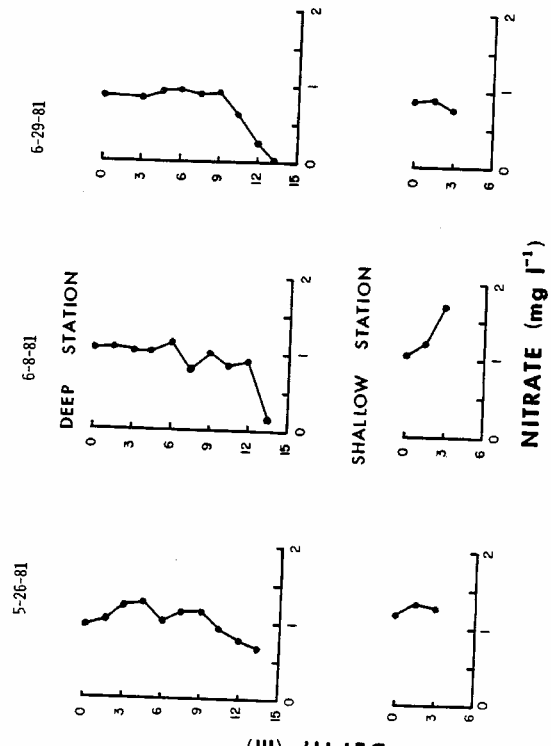

5-26-81
6-8-81
6-29-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRATE (mg l⁻¹)
0
3
6
9
12
15
1
2

Fig. 11d.

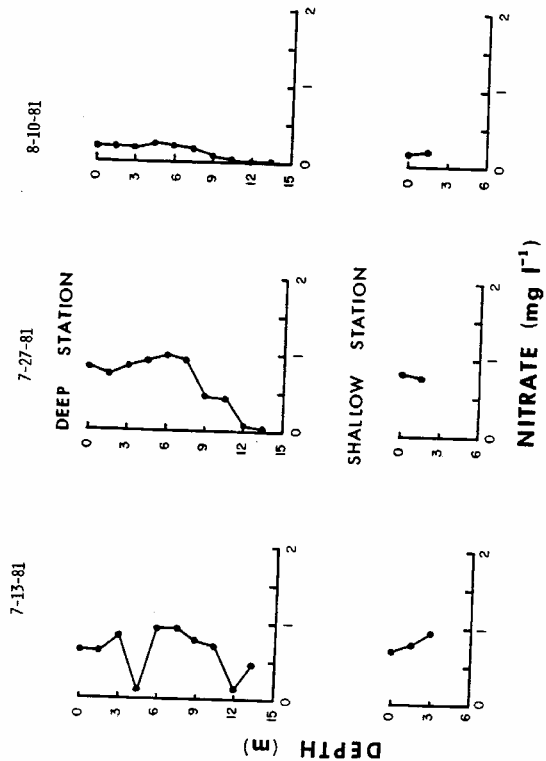

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRATE (mg l⁻¹)
0
3
6
9
12
15
0
1
2

Fig. 11e.

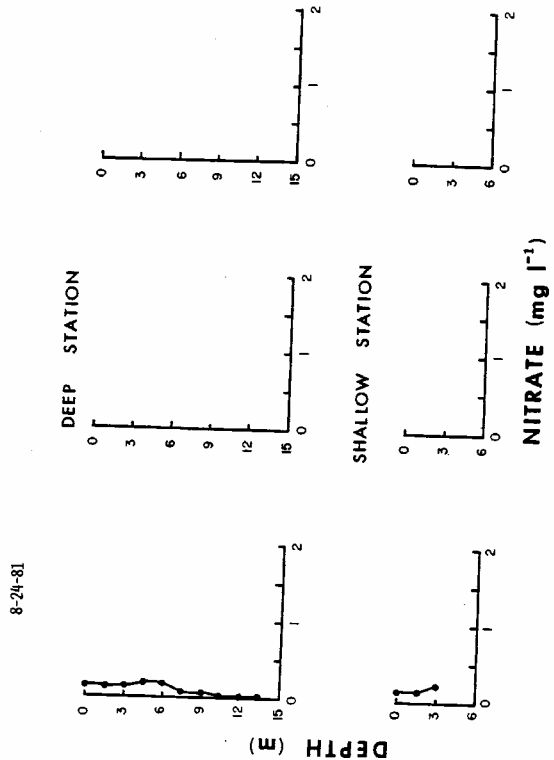

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
NITRATE (mg l⁻¹)
0
3
6
9
12
15
0
1
2

Fig. 12a-e. Temporal variation in organic nitrogen profiles at the deep and shallow stations of Lake Waubee.

Fig. 12a.

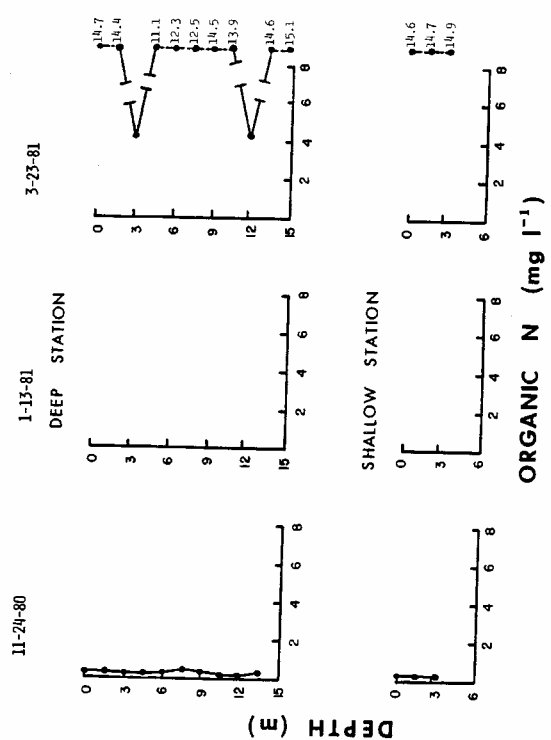

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC N (mg l⁻¹)
14.7
14.4
11.1
12.3
12.5
14.5
13.9
14.6
15.1
14.6
14.7
14.9

Fig. 12b.

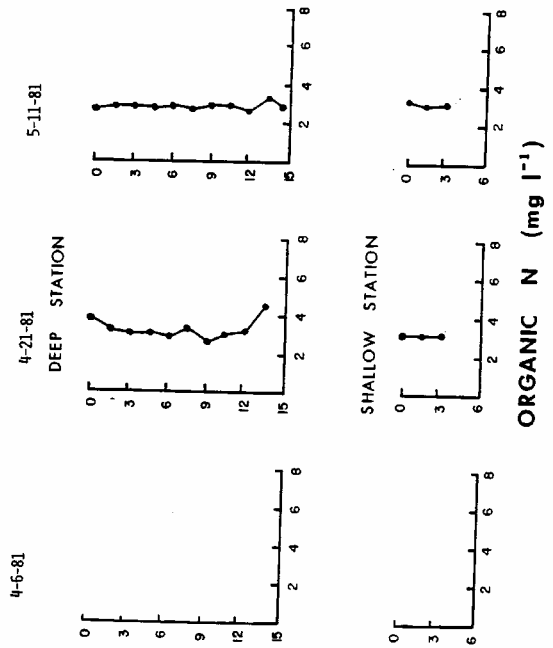

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC N (mg l⁻¹)

Fig. 12c.

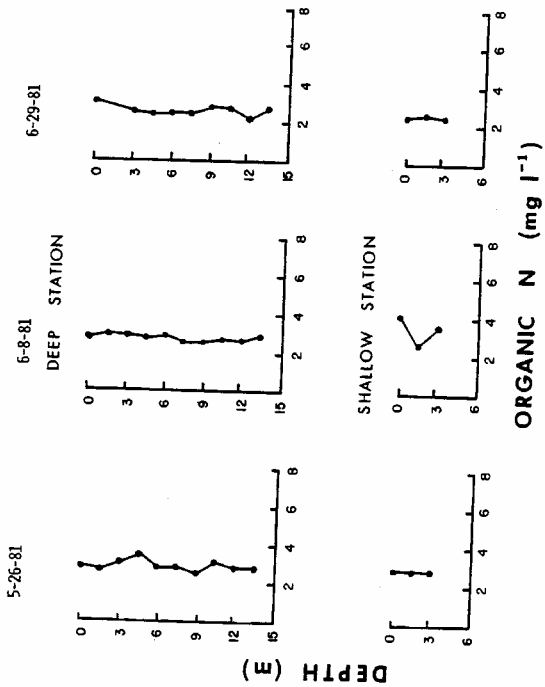

5-26-81
6-8-81
6-29-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC N (mg l⁻¹)

Fig. 12d.

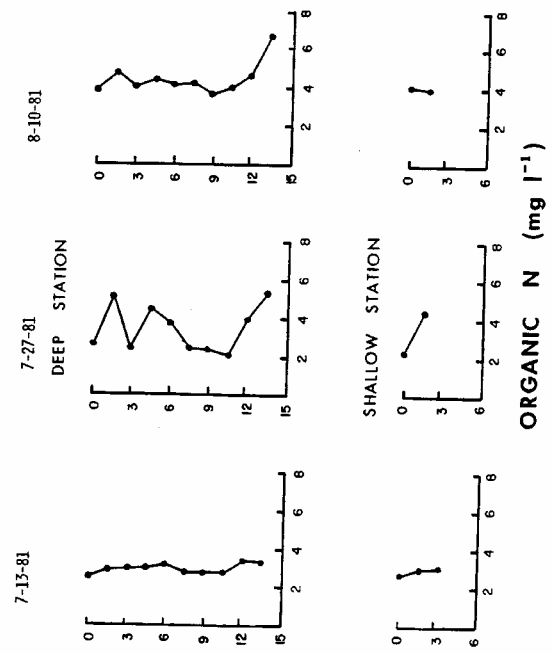

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC N (mg l⁻¹)

Fig. 12e.

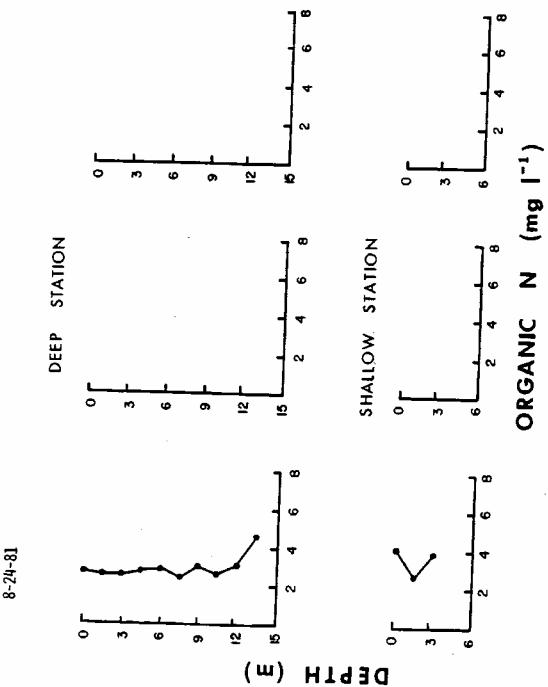


Fig. 13a-d. Temporal variation in silica profiles at the deep and shallow stations of Lake Waubee.

Fig. 13a.

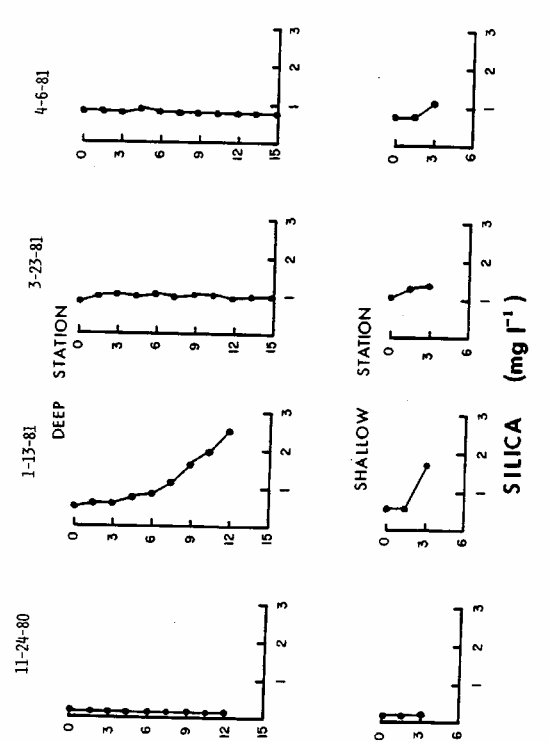

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
SILICA (mg l⁻¹)

Fig. 13b.

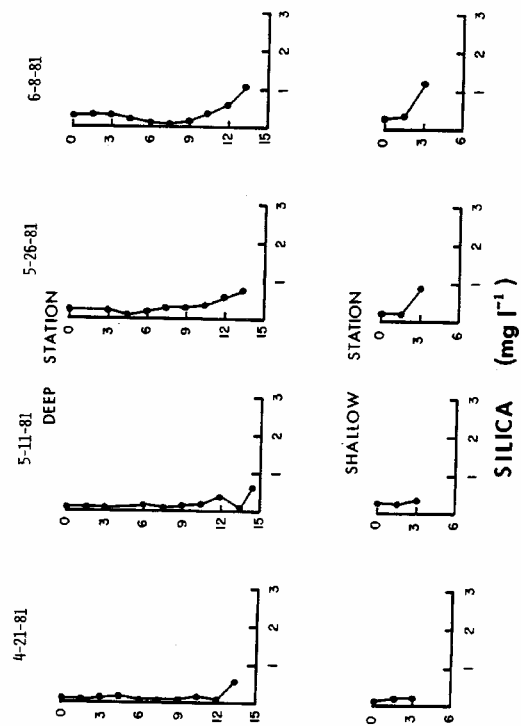

4-21-81
5-11-81
DEEP STATION
5-26-81
6-8-81
SHALLOW STATION
DEPTH (m)
SILICA (mg l⁻¹)

Fig. 13c.

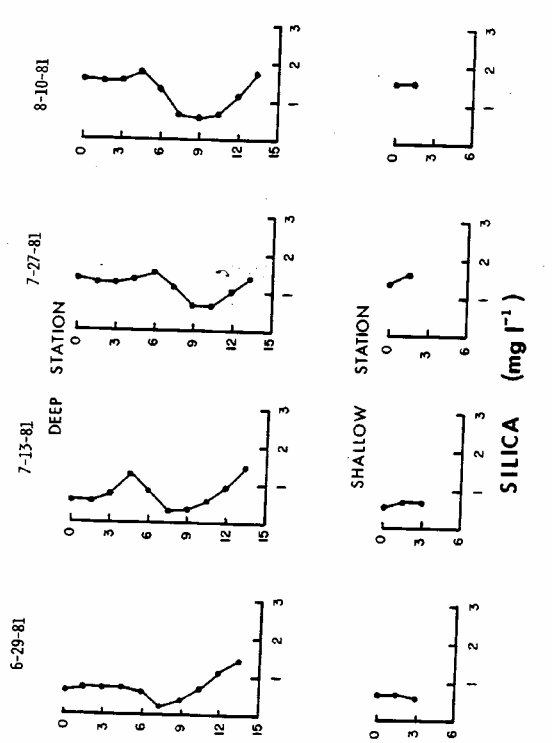

6-29-81
7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
SILICA (mg l⁻¹)

Fig. 13d.

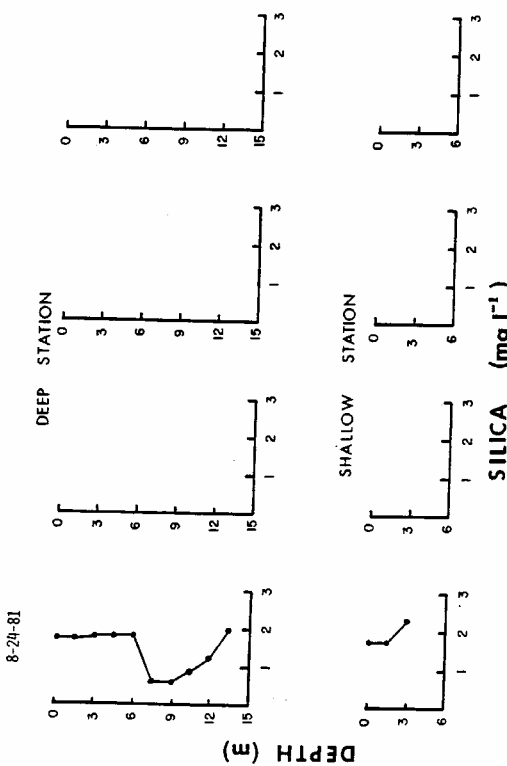


Fig. 14a-e. Temporal variation in total residue profiles at the deep and shallow stations of Lake Waubee.

Fig. 14a.

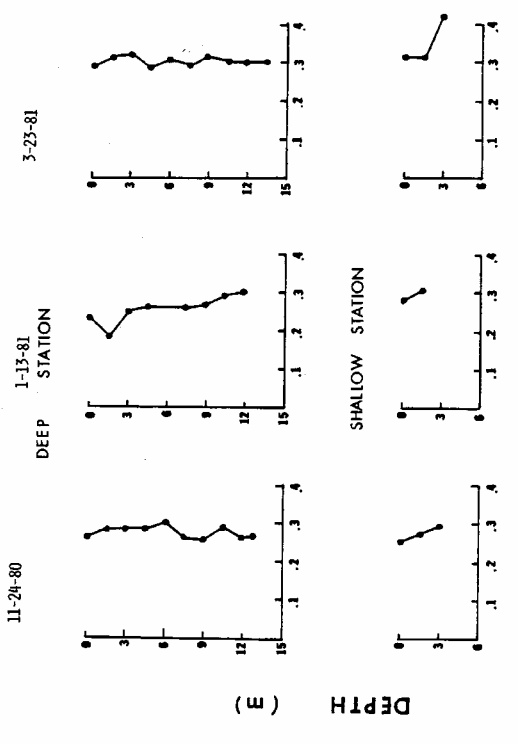

11-24-80
DEEP STATION
1-13-81
3-23-81
SHALLOW STATION
DEPTH (m)
TOTAL RESIDUE (g l⁻¹)

Fig. 14b.

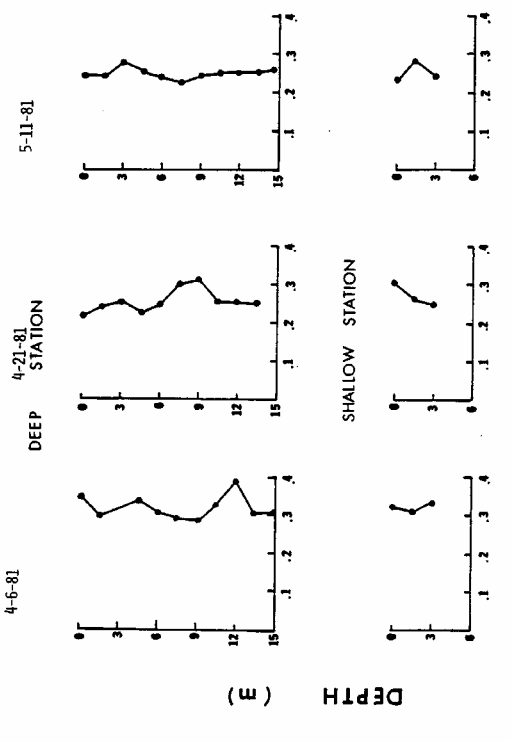

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL RESIDUE (g l⁻¹)

Fig. 14c.

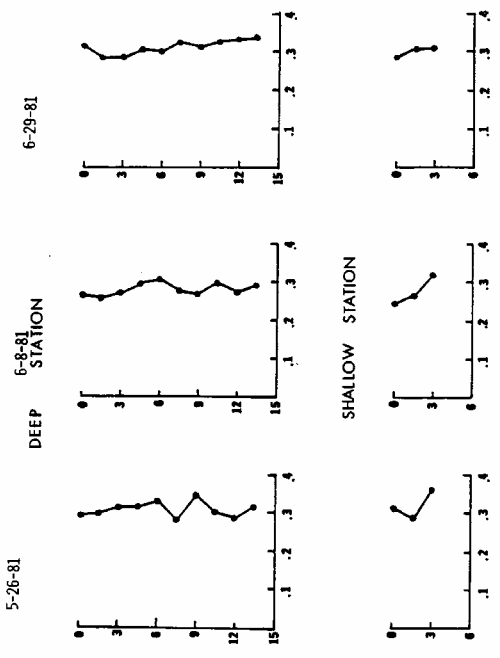

5-26-81
DEEP
6-8-81
STATION
6-29-81
SHALLOW STATION
DEPTH (m)
TOTAL RESIDUE (g l⁻¹)

Fig. 14d.

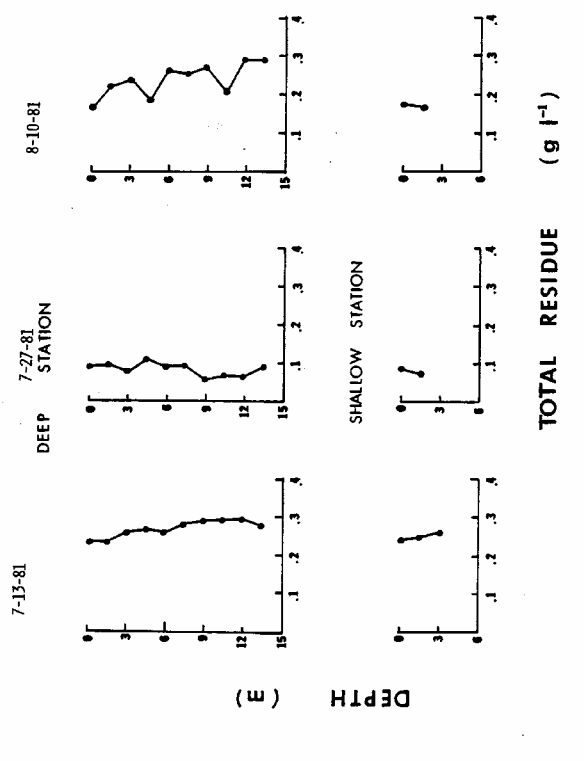

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL RESIDUE (g l⁻¹)

Fig. 14e.

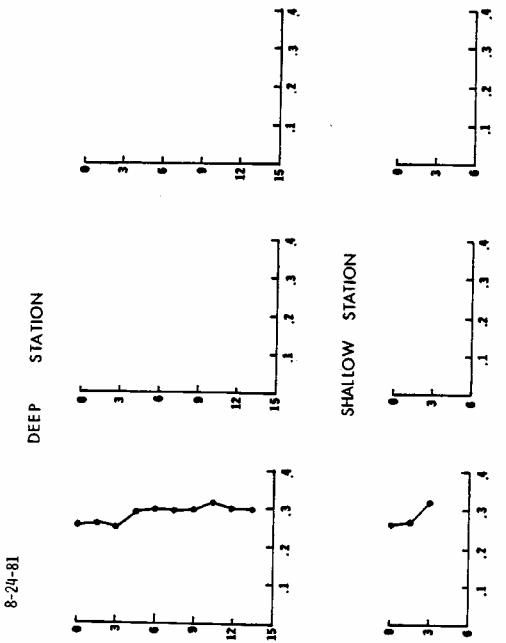

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL RESIDUE (g l⁻¹)

Fig. 15a-e. Temporal variation in organic residue profiles at the deep and shallow stations of Lake Waubee.

Fig. 15a.

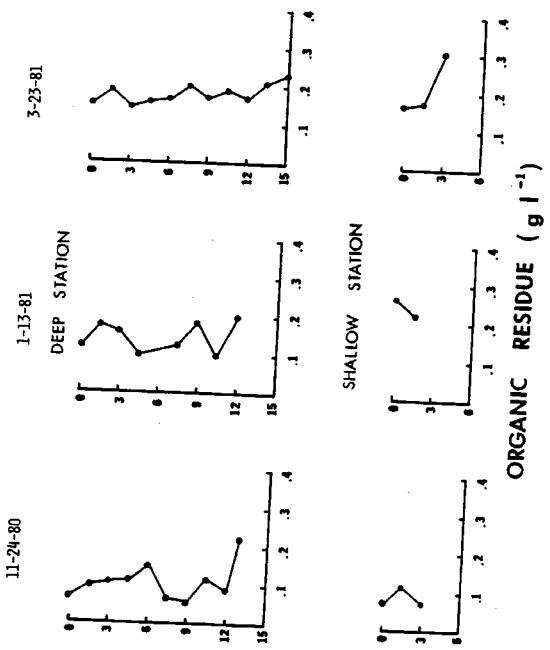

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC RESIDUE (g l⁻¹)

Fig. 15b.

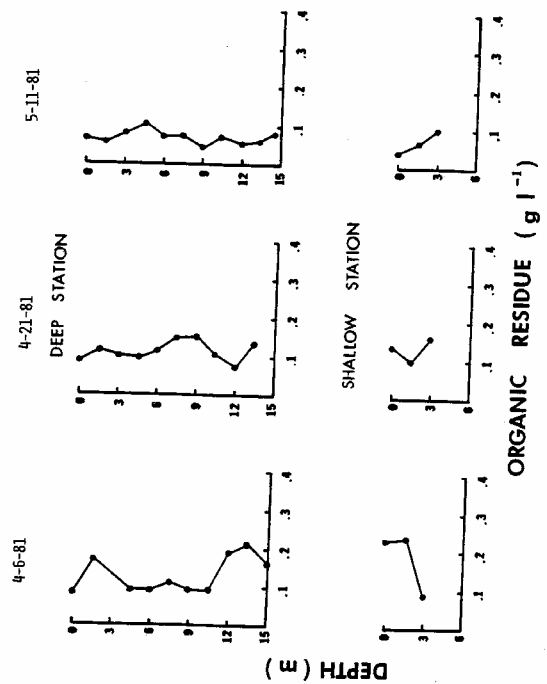

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC RESIDUE (g l⁻¹)

Fig. 15c.

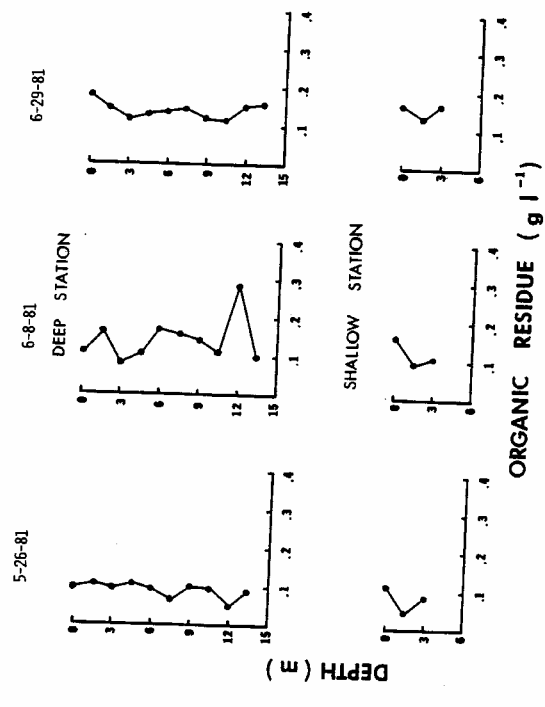

5-26-81
6-8-81
6-29-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC RESIDUE (g l⁻¹)

Fig. 15d.

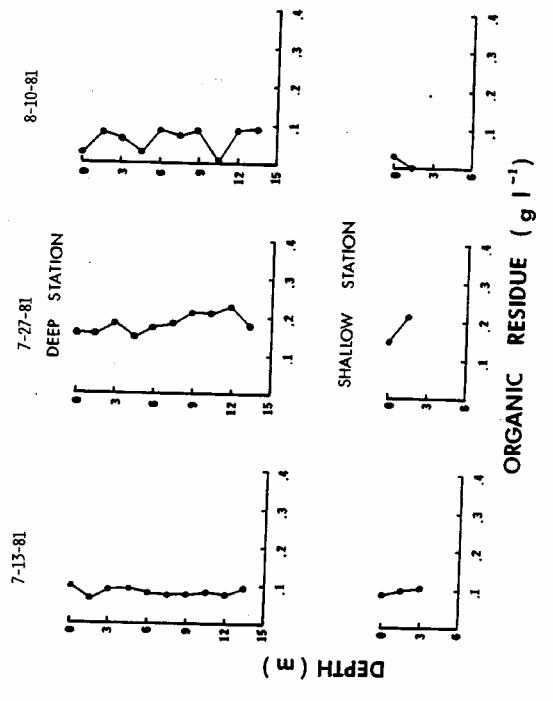

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC RESIDUE (g l⁻¹)

Fig. 15e.

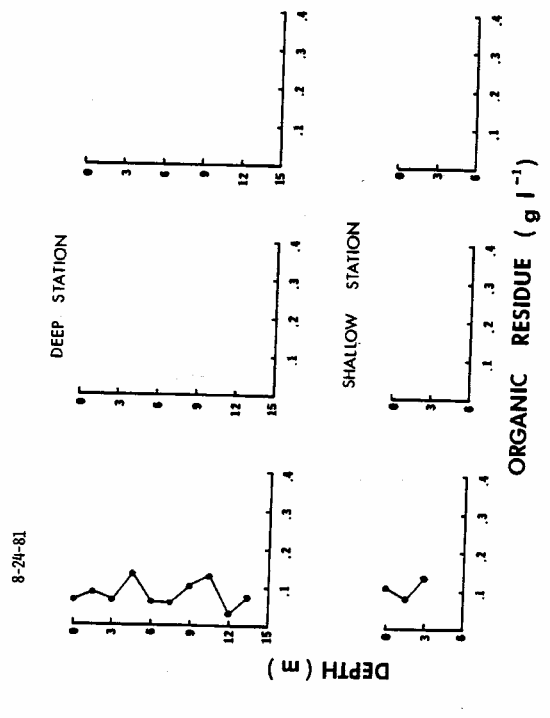

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
ORGANIC RESIDUE (g l⁻¹)
0
3
6
9
12
15
.1
.2
.3
.4

Fig. 16a-e. Temporal variation in total particulate matter profiles at the deep and shallow stations of Lake Waubee.

Fig. 16a.

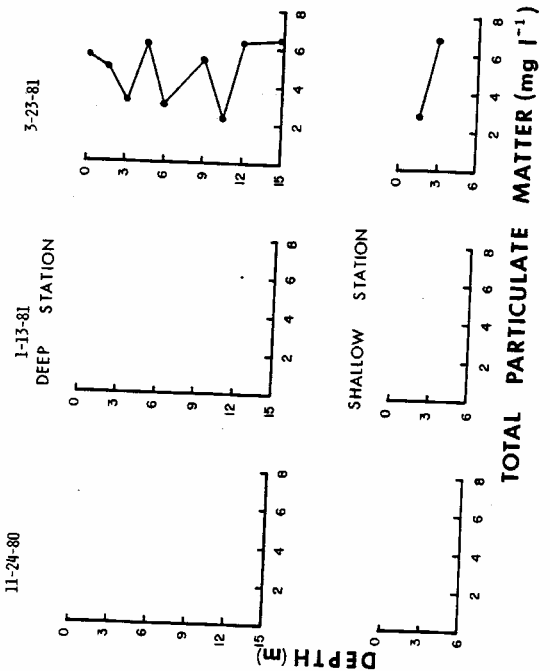

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL PARTICULATE MATTER (mg l⁻¹)

Fig. 16b.

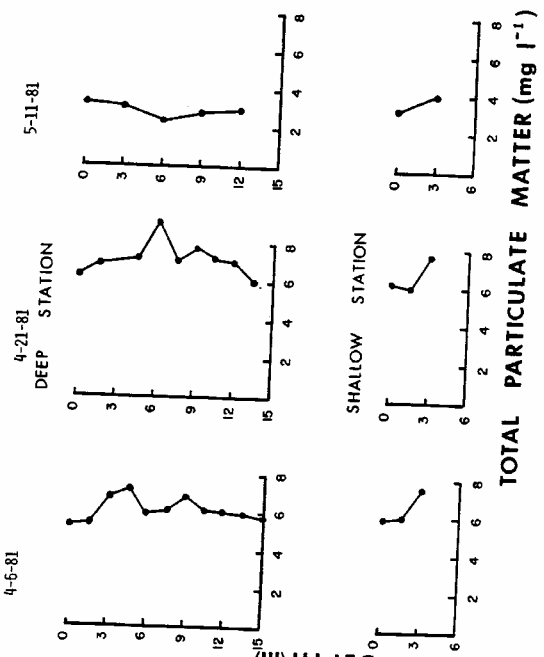

4-6-81
4-21-81
DEEP STATION
5-11-81
SHALLOW STATION
DEPTH (m)
TOTAL PARTICULATE MATTER (mg l⁻¹)

Fig. 16c.

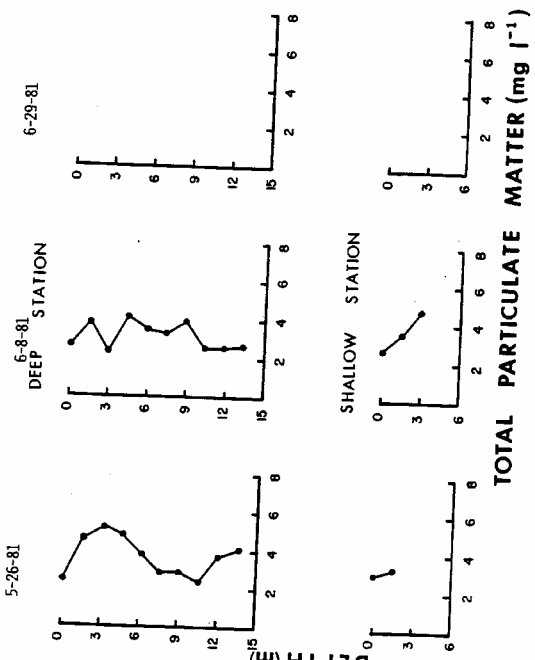

5-26-81
6-8-81
DEEP STATION
6-29-81
SHALLOW STATION
DEPTH (m)
TOTAL PARTICULATE MATTER (mg l⁻¹)

Fig. 16d.

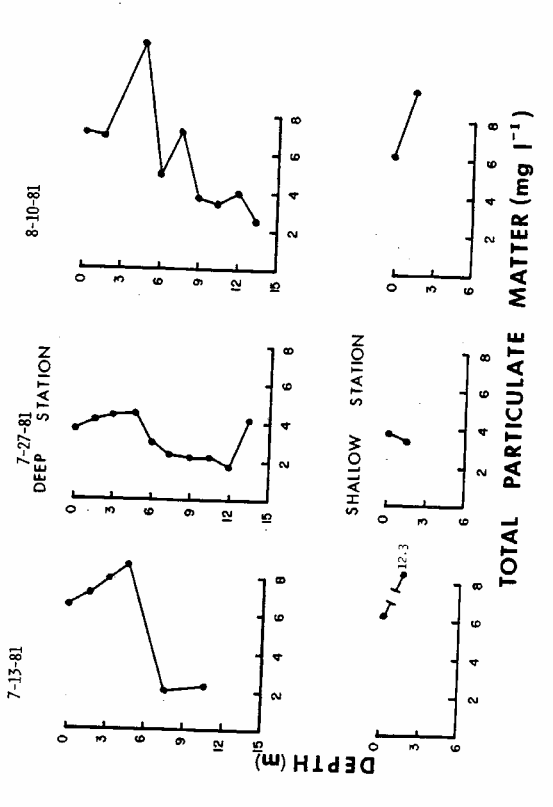

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL PARTICULATE MATTER (mg l⁻¹)
12.3

Fig. 16e.

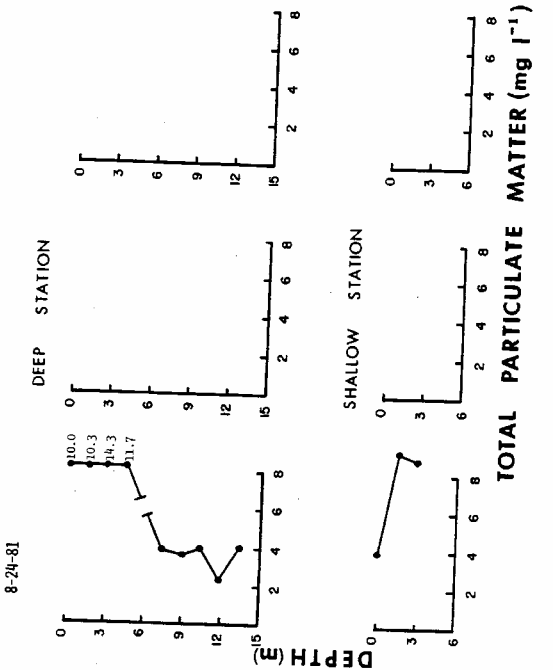

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL PARTICULATE MATTER (mg l⁻¹)
10.0
10.3
14.3
11.7

Fig. 17a-d. Temporal variation in particulate organic matter profiles at the deep and shallow stations of Lake Waubee.

Fig. 17a.

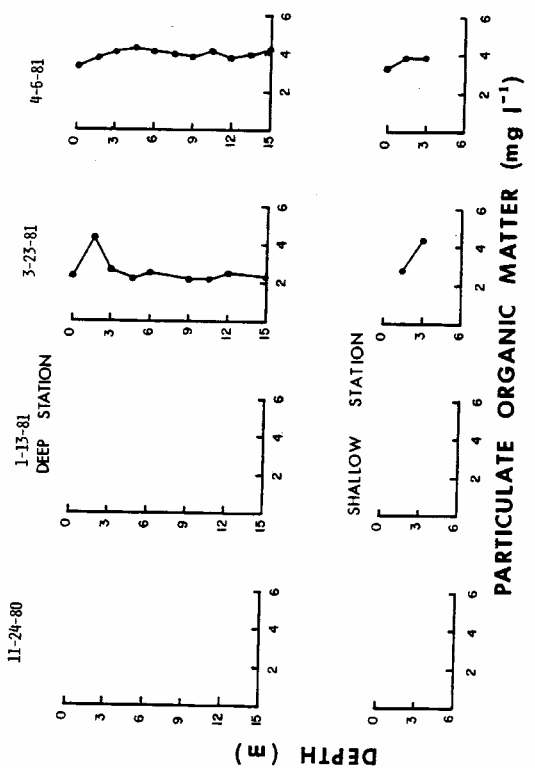

11-24-80
1-13-81
3-23-81
4-6-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
PARTICULATE ORGANIC MATTER (mg l⁻¹)

Fig. 17b.

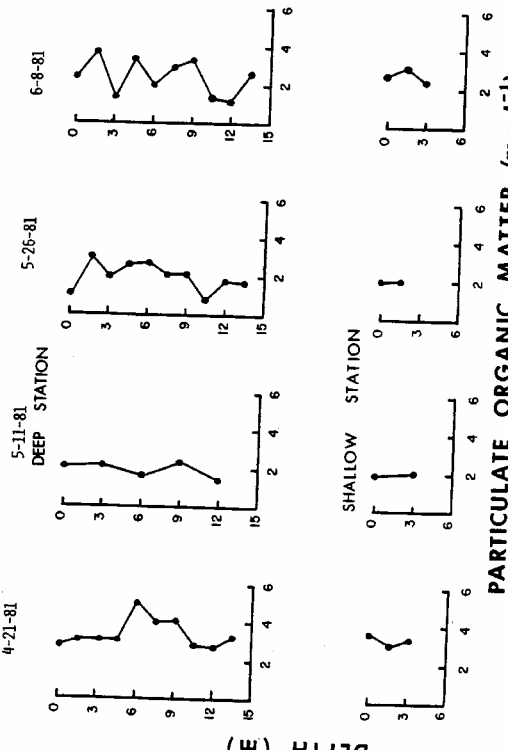

4-21-81
5-11-81
DEEP STATION
5-26-81
6-8-81
SHALLOW STATION
DEPTH (m)
PARTICULATE ORGANIC MATTER (mg l⁻¹)

Fig. 17c.

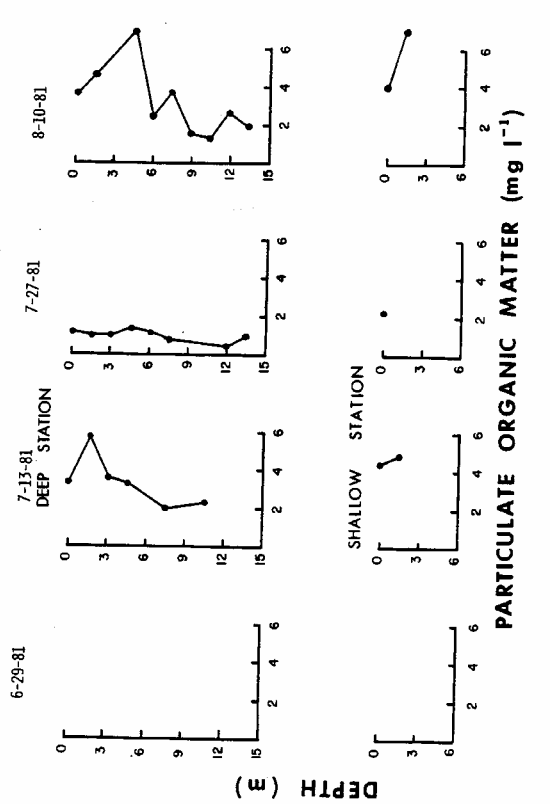

6-29-81
7-13-81
DEEP STATION
7-27-81
8-10-81
SHALLOW STATION
DEPTH (m)
PARTICULATE ORGANIC MATTER (mg l⁻¹)

Fig. 17d.

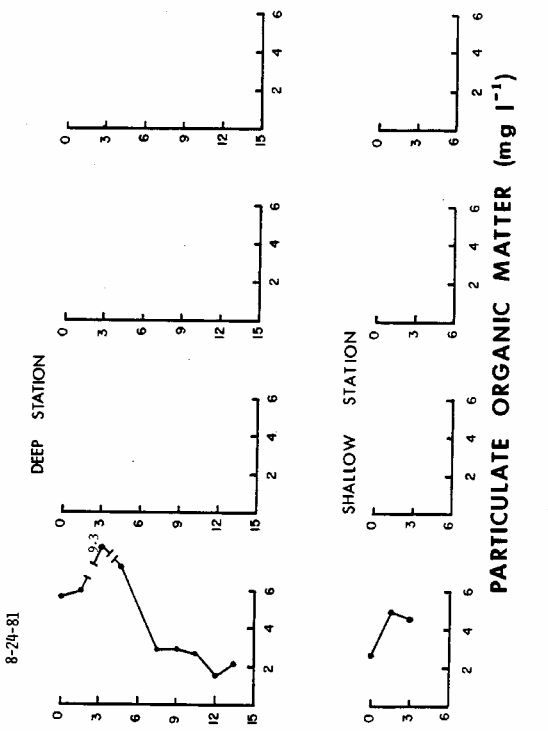

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
PARTICULATE ORGANIC MATTER (mg l⁻¹)

Fig. 18a-e. Temporal variation in total alkalinity profiles at the deep and shallow stations of Lake Waubee.

Fig. 18a.

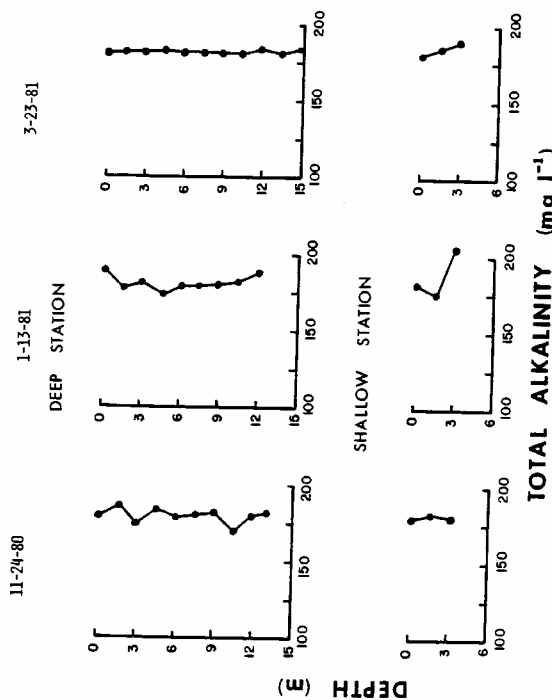

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL ALKALINITY (mg l⁻¹)

Fig. 18b.

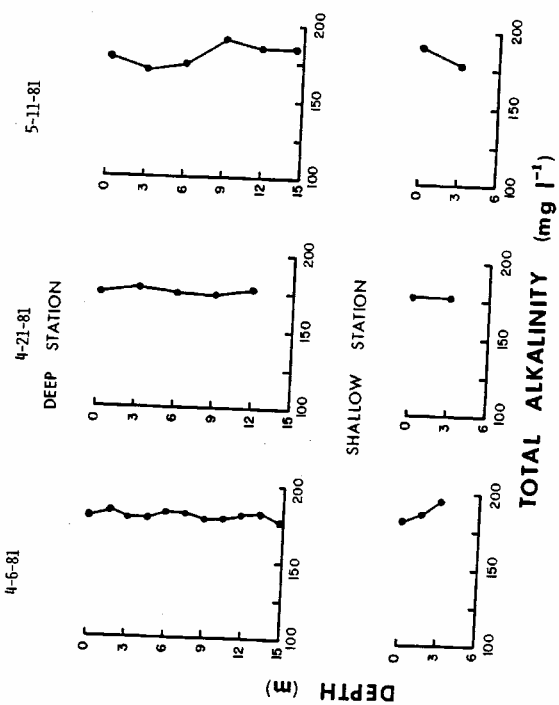

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL ALKALINITY (mg l⁻¹)
0
3
6
9
12
15
100
150
200

Fig. 18c.

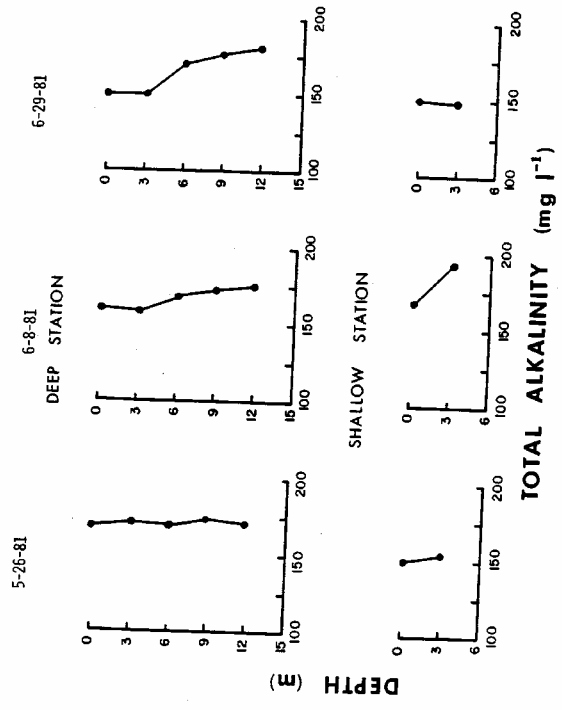

5-26-81
6-8-81
6-29-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL ALKALINITY (mg l⁻¹)
0
3
6
9
12
15
100
150
200

Fig. 18d.

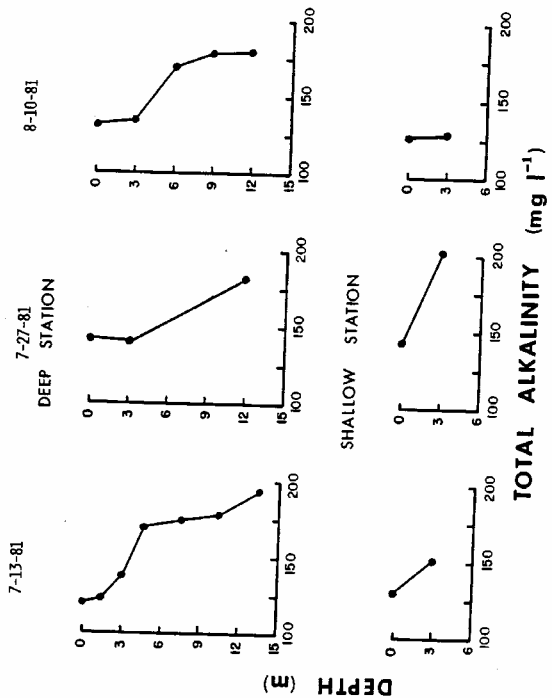

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL ALKALINITY (mg l⁻¹)
0
3
6
9
12
15
100
150
200

Fig. 18e.

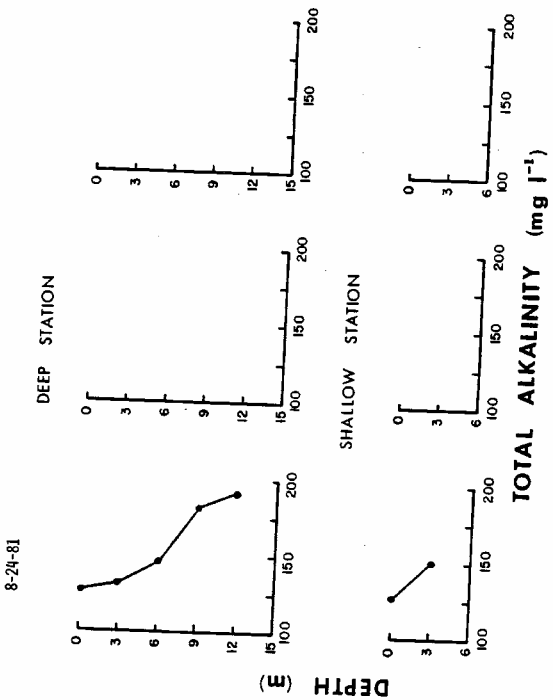

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
TOTAL ALKALINITY (mg l⁻¹)
0
3
6
9
12
15
100
150
200

Fig. 19a-e. Temporal variation in chlorophyll *a* profiles at the deep and shallow stations of Lake Waubee.

Fig. 19a.

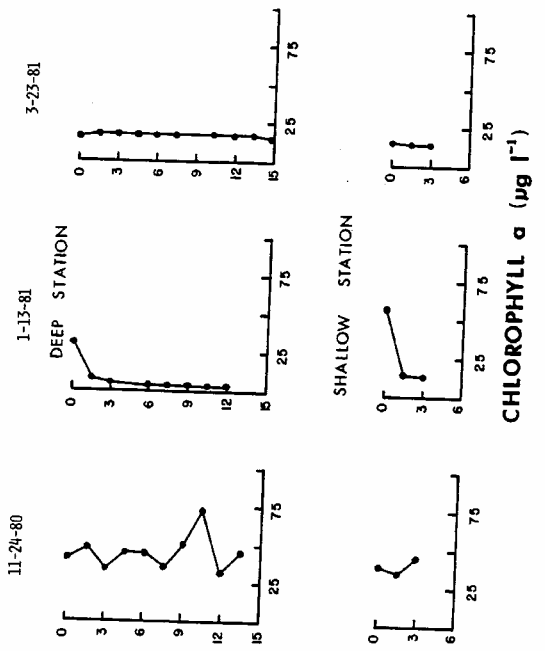

11-24-80
1-13-81
3-23-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
CHLOROPHYLL a (µg l⁻¹)
0
3
6
9
12
15
25
75

Fig. 19b.

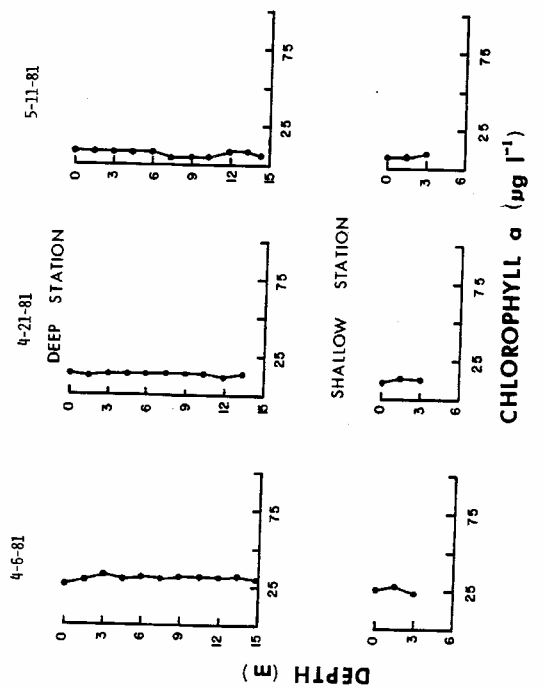

4-6-81
4-21-81
5-11-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
CHLOROPHYLL a (µg l⁻¹)
0
3
6
9
12
15
25
75

Fig. 19c.

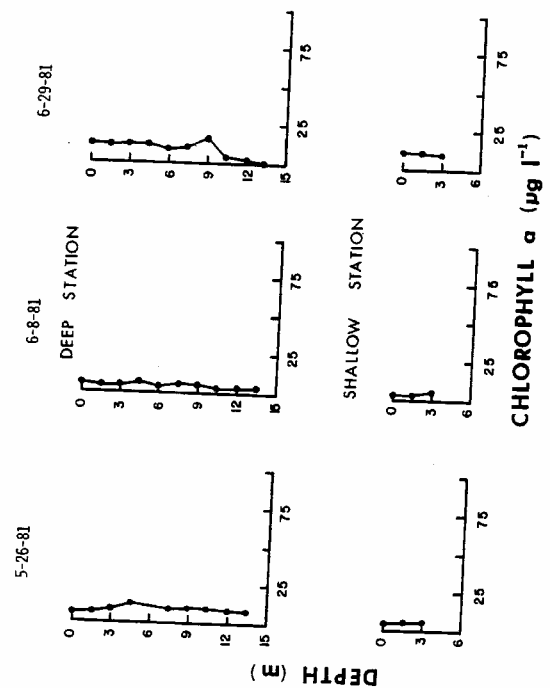

5-26-81
6-8-81
6-29-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
CHLOROPHYLL a (μg l⁻¹)

Fig. 19d.

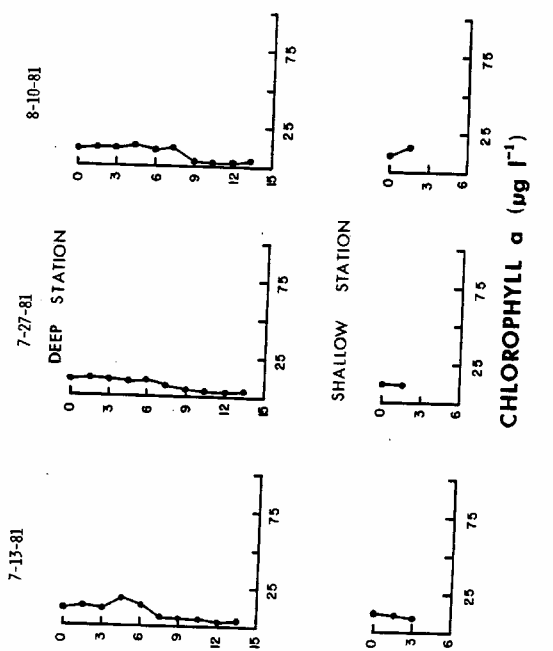

7-13-81
7-27-81
8-10-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
CHLOROPHYLL a (µg l⁻¹)

Fig. 19e.

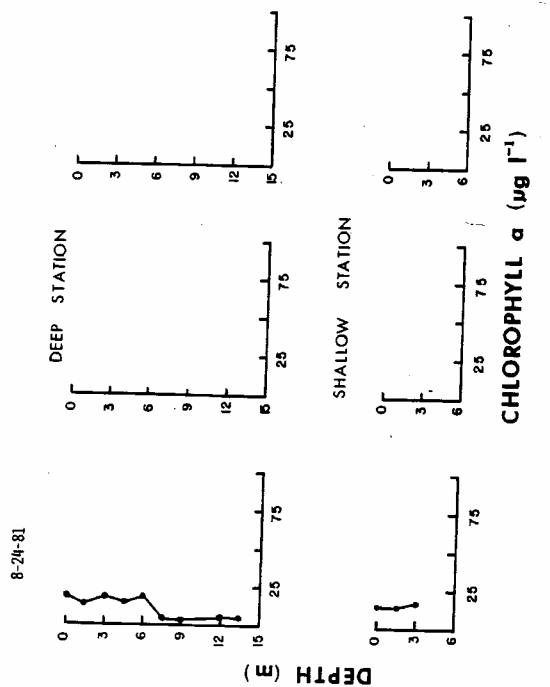

8-24-81
DEEP STATION
SHALLOW STATION
DEPTH (m)
CHLOROPHYLL a (µg l⁻¹)
0
3
6
9
12
15
25
75

Fig. 20a-k. Phytoplankton community composition on various dates in Lake Waubee.

Fig. 20a.

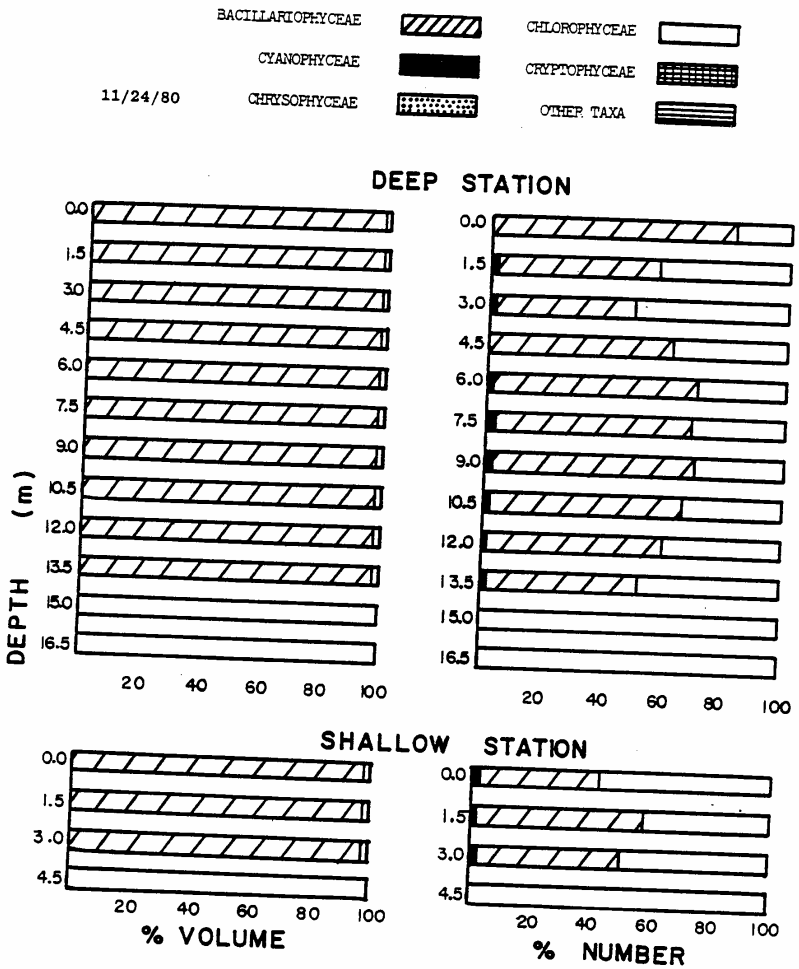

BACILLARIOPHYCEAE
CYANOPHYCEAE
CHRYSOPHYCEAE
CHLOROPHYCEAE
CRYPTOPHYCEAE
OTHER TAXA
11/24/80
DEEP STATION
SHALLOW STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
% VOLUME
% NUMBER

Fig. 20b.

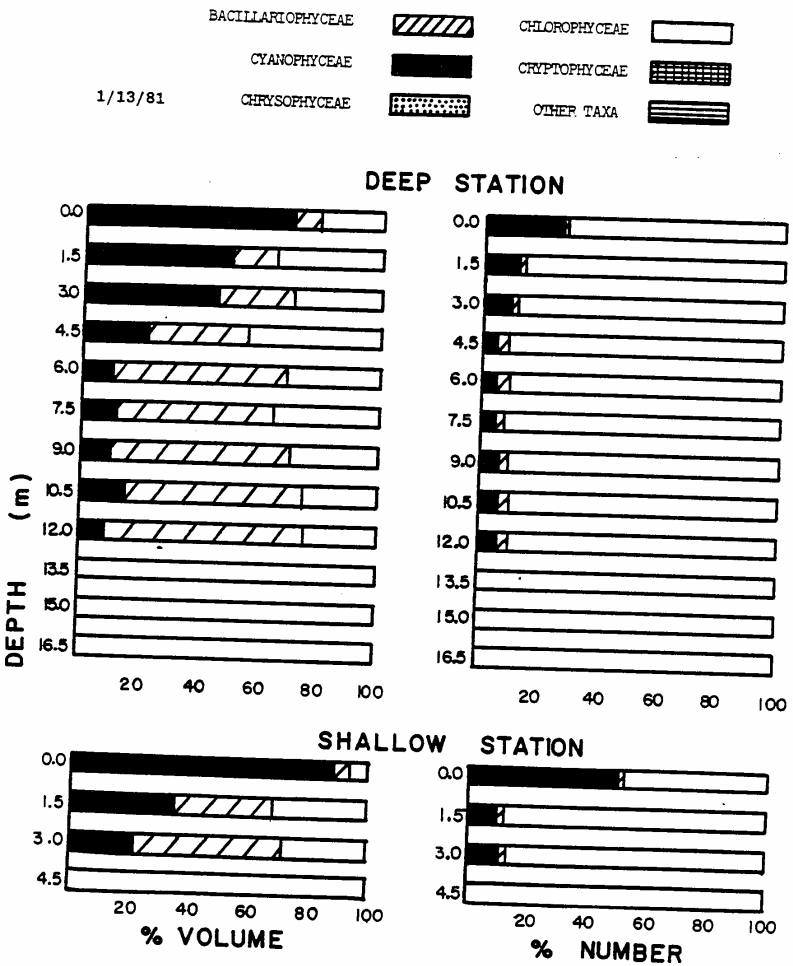

BACILLARIOPHYCEAE
CYANOPHYCEAE
CHRYSOPHYCEAE
CHLOROPHYCEAE
CRYPTOPHYCEAE
OTHER TAXA
1/13/81
DEEP STATION
SHALLOW STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
% VOLUME
% NUMBER

Fig. 20c.

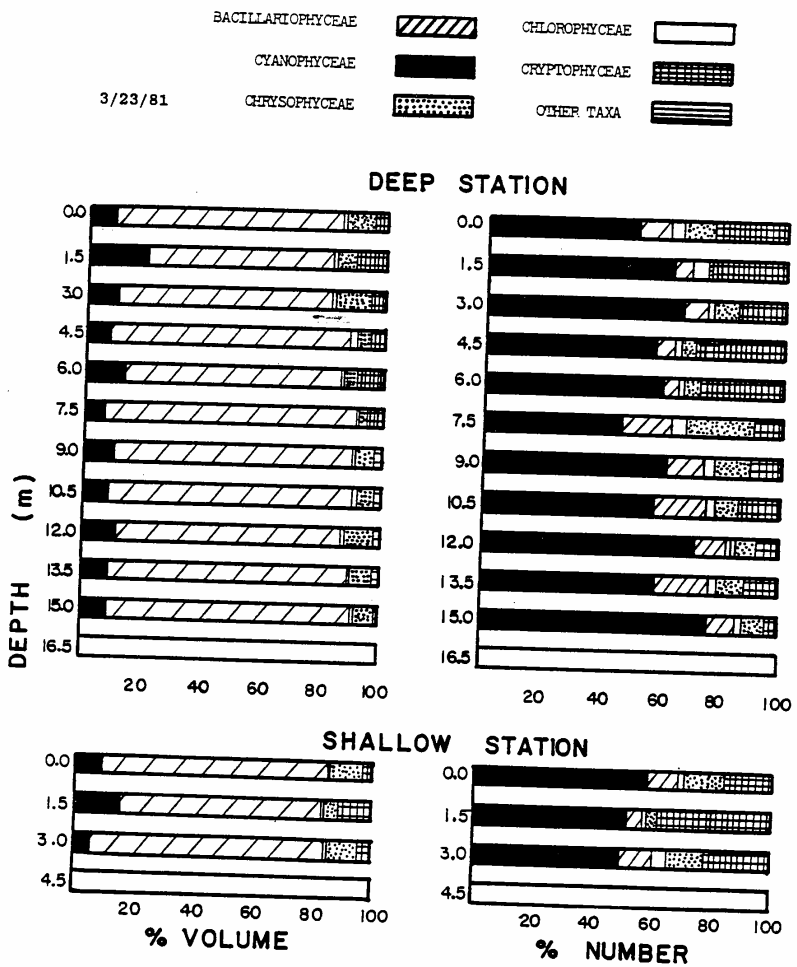

BACILLARIOPHYCEAE
CHLOROPHYCEAE
CYANOPHYCEAE
CRYPTOPHYCEAE
3/23/81
CHRYSOPHYCEAE
OTHER TAXA
DEEP STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20 40 60 80 100
SHALLOW STATION
% VOLUME
% NUMBER

Fig. 20d.

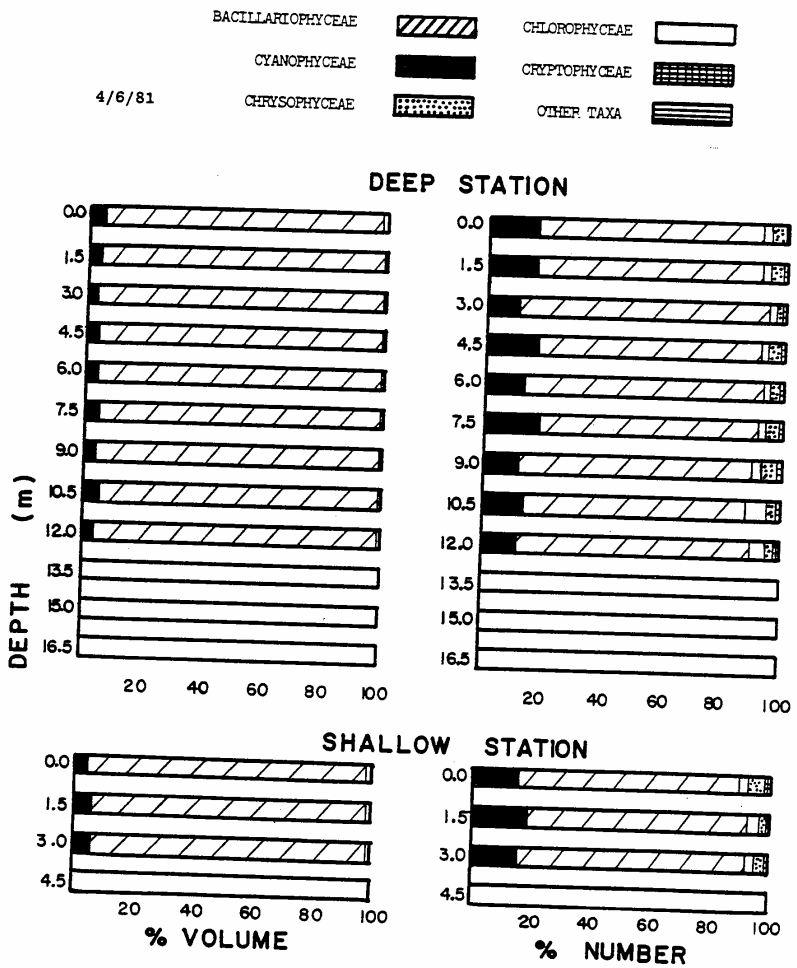

BACILLARIOPHYCEAE
CYANOPHYCEAE
CHRYSOPHYCEAE
CHLOROPHYCEAE
CRYPTOPHYCEAE
OTHER TAXA
4/6/81
DEEP STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
SHALLOW STATION
% VOLUME
% NUMBER

Fig. 20e.

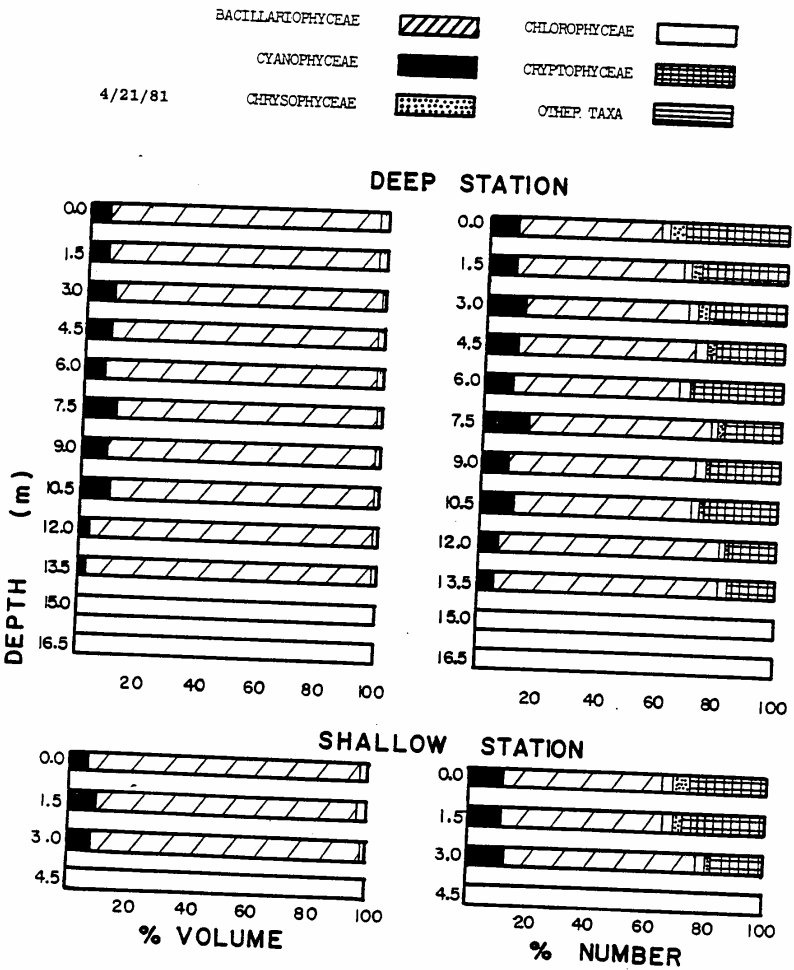

BACILLARIOPHYCEAE
CYANOPHYCEAE
CHRYSOPHYCEAE
CHLOROPHYCEAE
CRYPTOPHYCEAE
OTHER TAXA
4/21/81
DEEP STATION
SHALLOW STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
% VOLUME
% NUMBER

Fig. 20f.

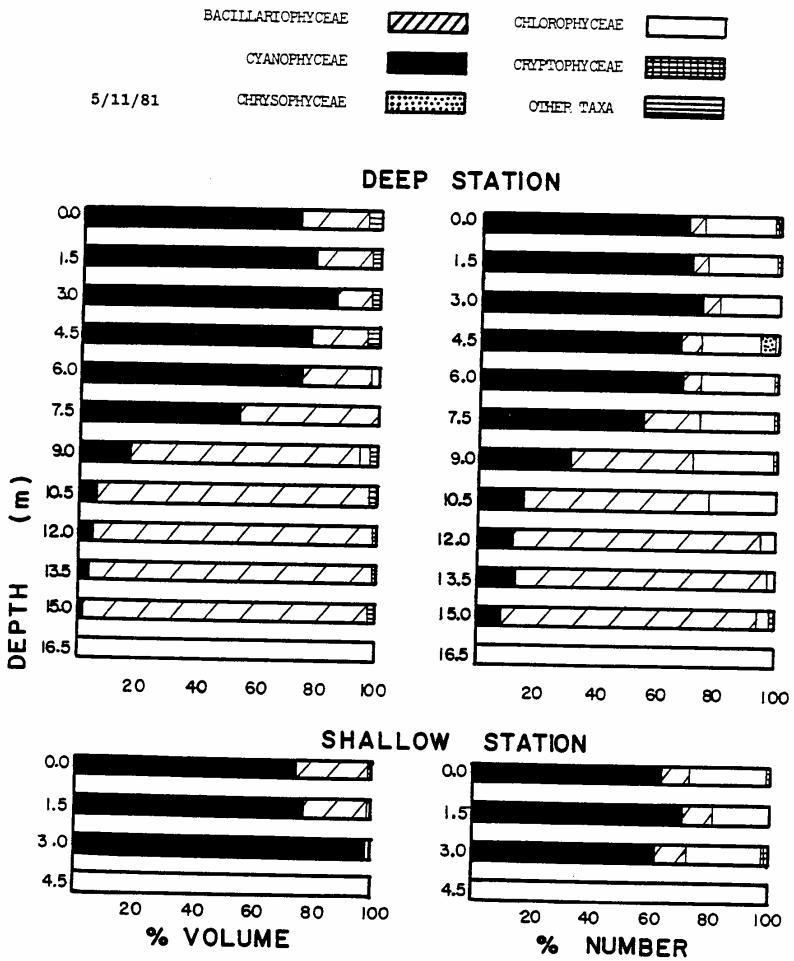

BACILLARIOPHYCEAE
CYANOPHYCEAE
5/11/81
CHRYSOPHYCEAE
CHLOROPHYCEAE
CRYPTOPHYCEAE
OTHER TAXA
DEEP STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
SHALLOW STATION
% VOLUME
% NUMBER

Fig. 20g.

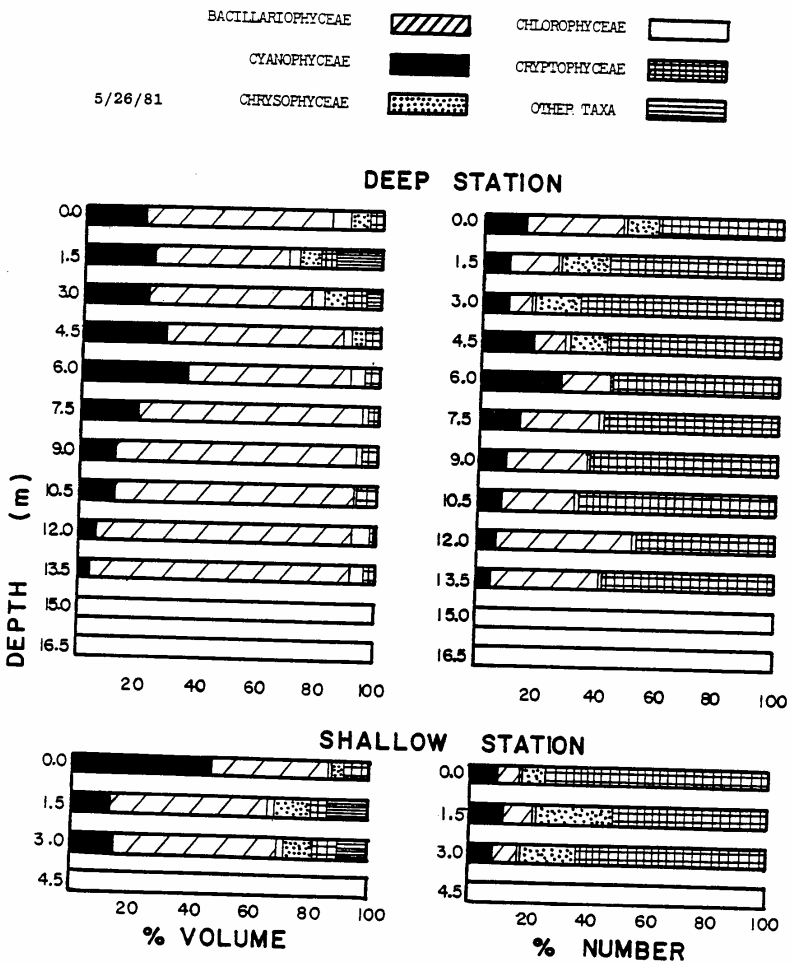

BACILLARIOPHYCEAE
CHLOROPHYCEAE
CYANOPHYCEAE
CRYPTOPHYCEAE
5/26/81
CHRYSOPHYCEAE
OTHER TAXA
DEEP STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
SHALLOW STATION
% VOLUME
% NUMBER

Fig. 20h.

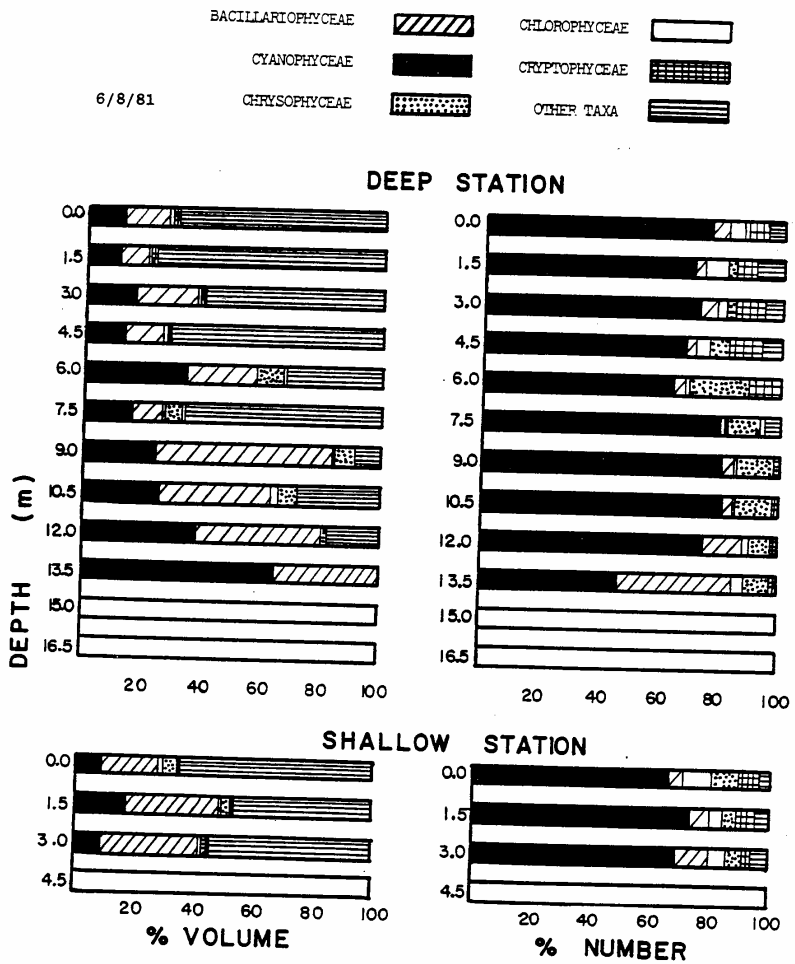

BACILLARIOPHYCEAE
CYANOPHYCEAE
CHRYSOPHYCEAE
CHLOROPHYCEAE
CRYPTOPHYCEAE
OTHER TAXA
6/8/81
DEEP STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
SHALLOW STATION
% VOLUME
% NUMBER

Fig. 201.

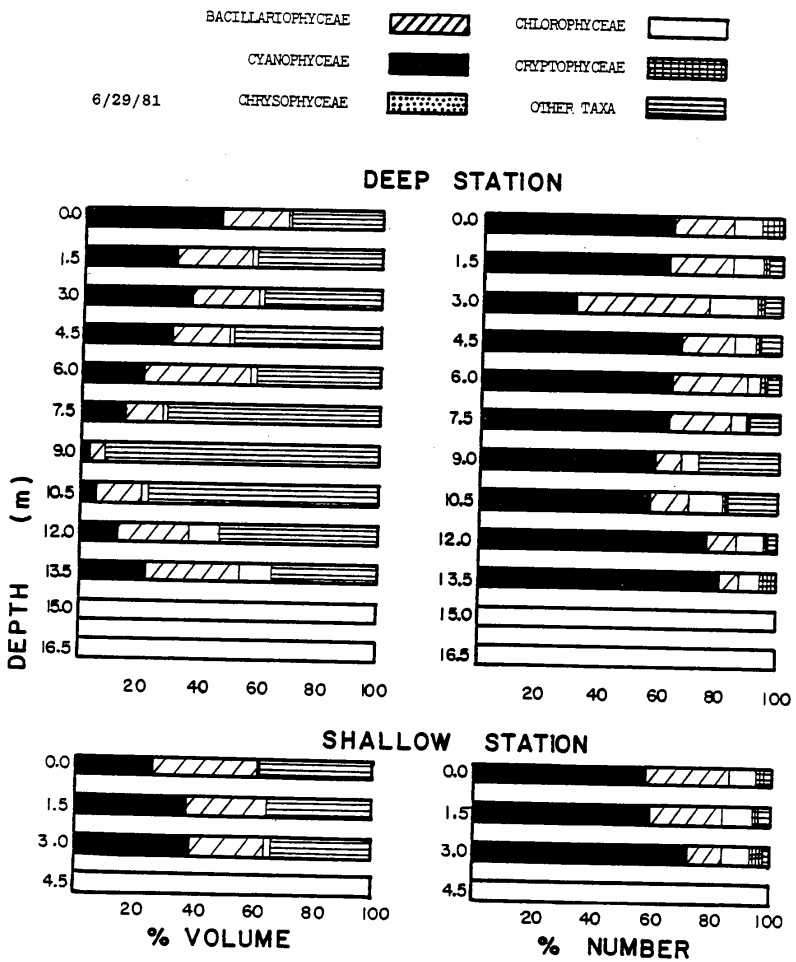

BACILLARIOPHYCEAE
CHLOROPHYCEAE
CYANOPHYCEAE
CRYPTOPHYCEAE
6/29/81
CHRYSOPHYCEAE
OTHER TAXA
DEEP STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
SHALLOW STATION
% VOLUME
% NUMBER

Fig. 20j.

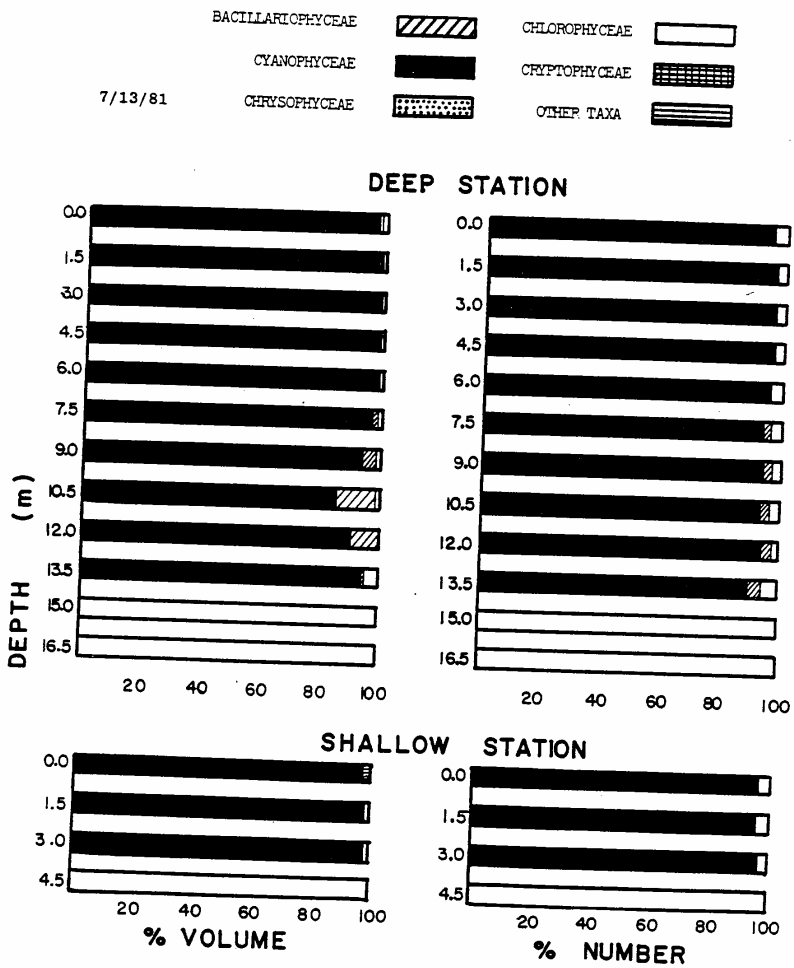

BACILLARIOPHYCEAE
CYANOPHYCEAE
CHRYSOPHYCEAE
CHLOROPHYCEAE
CRYPTOPHYCEAE
OTHER TAXA
7/13/81
DEEP STATION
SHALLOW STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
% VOLUME
% NUMBER

Fig. 20k.

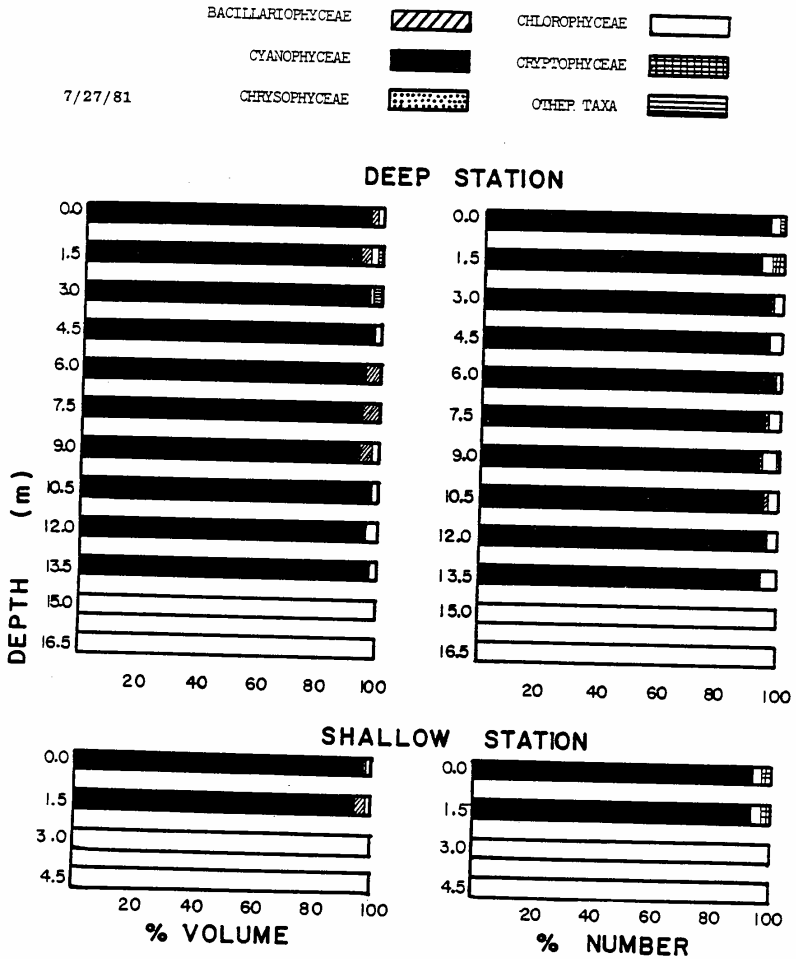

BACILLARIOPHYCEAE
CHLOROPHYCEAE
CYANOPHYCEAE
CRYPTOPHYCEAE
7/27/81
CHRYSOPHYCEAE
OTHER TAXA
DEEP STATION
DEPTH (m)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
20
40
60
80
100
SHALLOW STATION
% VOLUME
% NUMBER

Fig. 21a-b. Phytoplankton numbers and volume at the deep (a) and shallow (b) stations in Lake Waubee.

Fig. 21a.

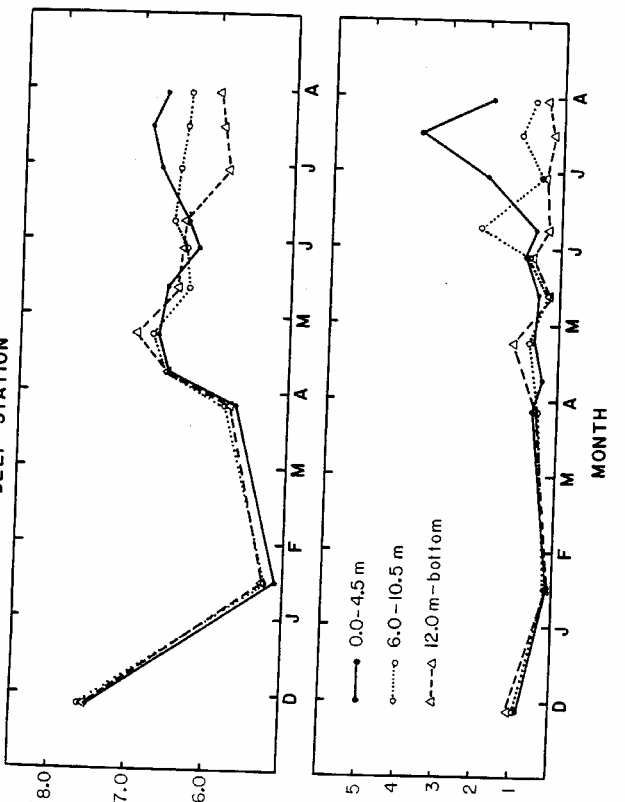

DEEP STATION
LOG X̄ VOL. (μm³ ml⁻¹)
8.0
7.0
6.0
X̄ CELLS ml⁻¹ (x10³)
5
4
3
2
1
0.0-4.5 m
6.0-10.5 m
12.0 m-bottom
D
J
F
M
A
M
J
J
A
MONTH

Fig. 21b.

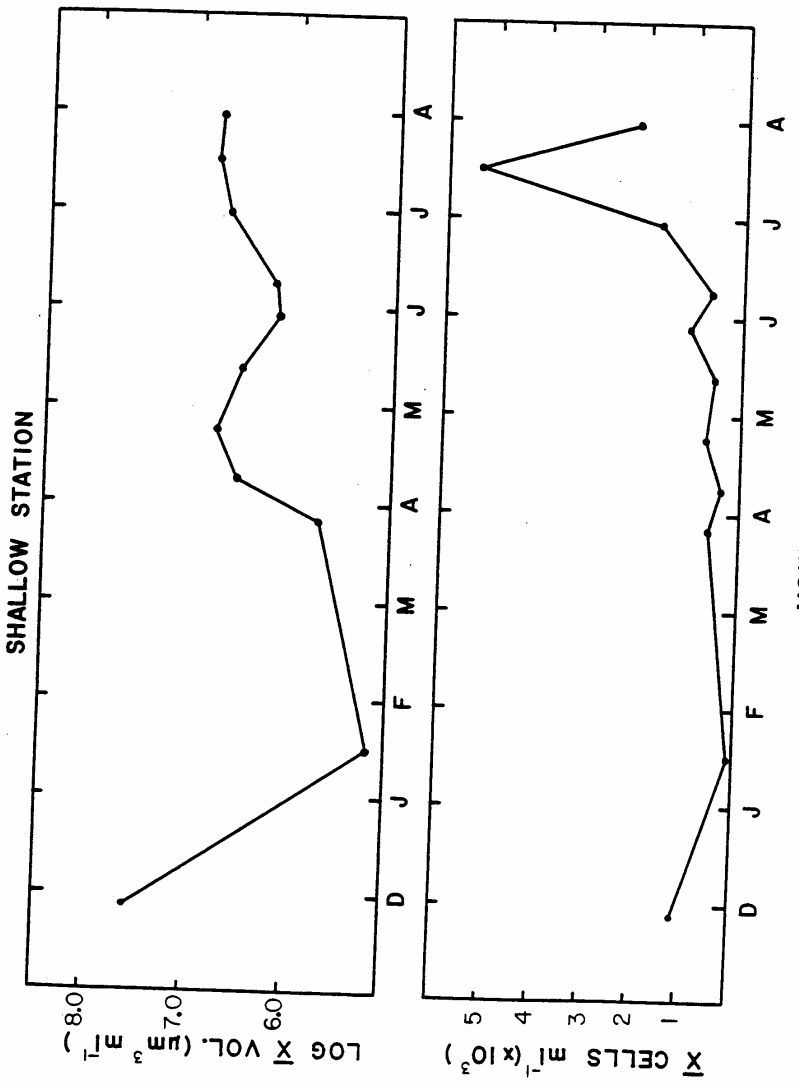

SHALLOW STATION
LOG X̄ VOL. (μm³ ml⁻¹)
X̄ CELLS ml⁻¹ (x 10³)
MONTH
D
J
F
M
A
M
J
J
A

Fig. 22. Integral photosynthesis on two dates in Lake Waubee.

Fig. 22

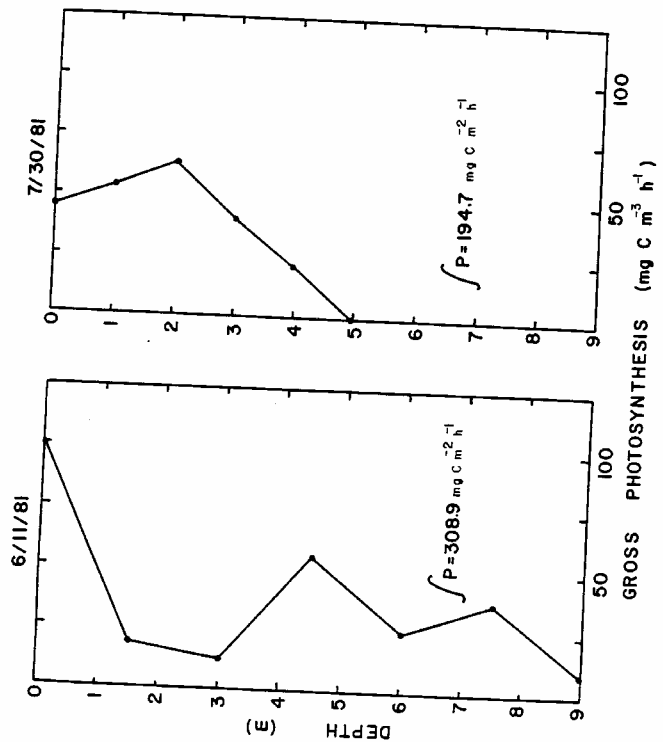

6/11/81
7/30/81
DEPTH (m)
GROSS PHOTOSYNTHESIS (mg C m⁻³ h⁻¹)
∫P=308.9 mg C m⁻² h⁻¹
∫P=194.7 mg C m⁻² h⁻¹

Fig. 23. Algal bioassay of Lake Waubee on August 10, 1981. See text for explaination of symbols.

Fig. 23.

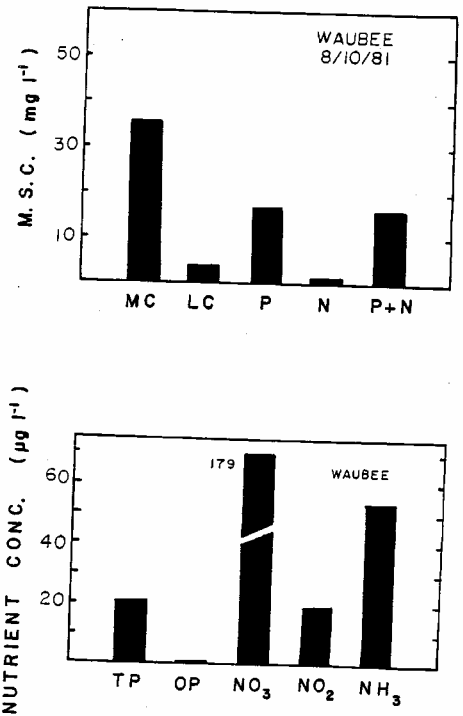

WAUBEE
8/10/81
M. S. C. (mg l⁻¹)
50
30
10
MC
LC
P
N
P+N
NUTRIENT CONC. (µg l⁻¹)
179
WAUBEE
60
40
20
TP
OP
NO3
NO2
NH3

Fig. 24. Temporal variation in the macrophyte biomass present in Lake Waubee during the 1981 growing season.

Fig. 24.

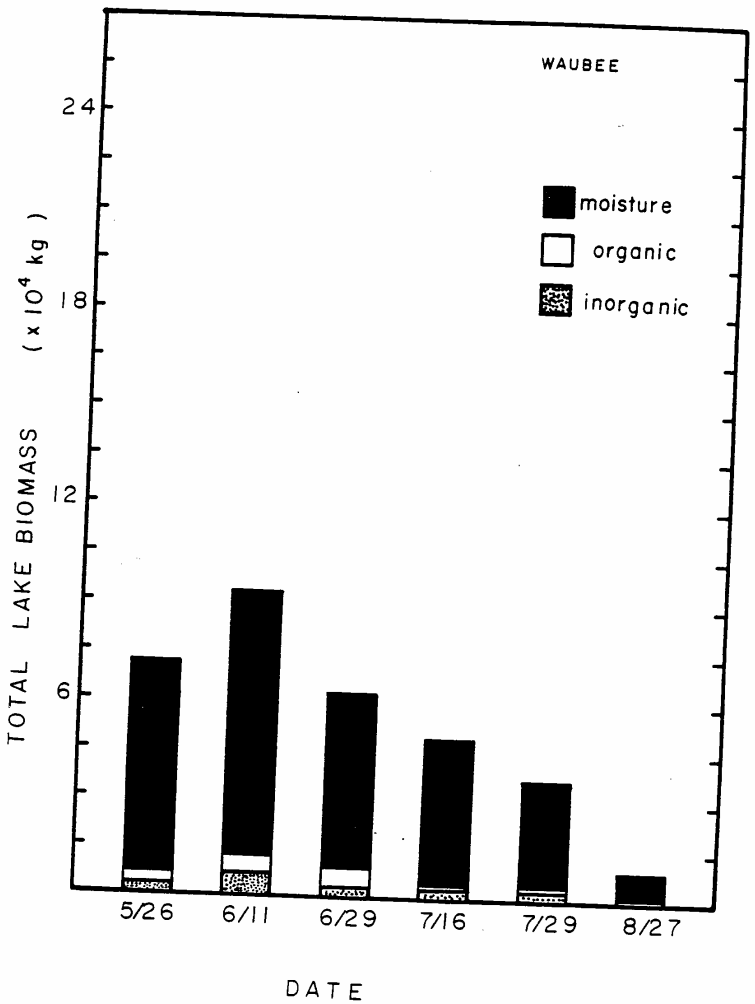

WAUBEE
moisture
organic
inorganic
24
18
12
6
TOTAL LAKE BIOMASS (x 10⁴ kg)
5/26
6/11
6/29
7/16
7/29
8/27
DATE

Fig. 25. Temporal variation in the nutrient pools present in the macrophyte community of Lake Waubee during the 1981 growing season.

Fig. 25.

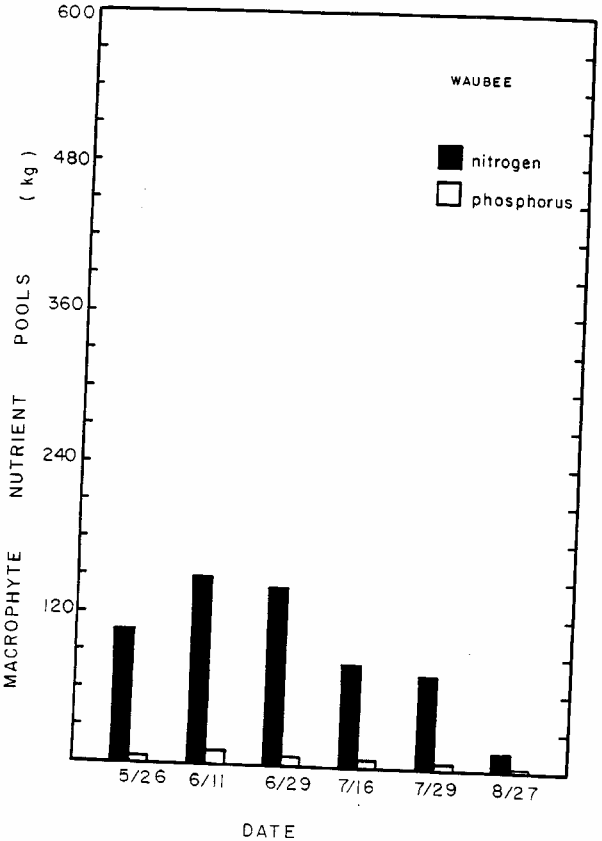

600
480
360
240
120
MACROPHYTE NUTRIENT POOLS (kg)
WAUBEE
nitrogen
phosphorus
5/26
6/11
6/29
7/16
7/29
8/27
DATE

TABLE 1.

Total attenuation (n) and non-chlorophyll attenuation (n_w) coefficients of the upper 6 m of Lake Waubee on various dates.

Date	n	n_w	$n_{w/n}$
11/24/80	0.66	0.00	0.00
3/23/81	0.66	0.40	0.61
4/6/81	0.79	0.31	0.39
4/21/81	0.70	0.49	0.70
6/29/81	0.75	0.59	0.79
7/30/81	0.73	0.56	0.77

TABLE 2.

Total coliform counts for Lake Waubee, the tributaries, and the outlet.

Site	4-21	5-26	6-29	7-13	7-27*	8-10
6	130	310	1700	1100	80(80)	3000(3000)
3	150	280	340	1300(650)	ND**	1100(1100)
5	540	290	1400	1100(550)	ND**	2800(2800)
4	ND**	310	1100	2400(1200)	ND**	2300(2300)
2	610	230	450	1400(700)	60(60)	1400(1400)
1	40	95	160	1100(550)	ND**	1300(1300)
7	20	30	100	150(75)	ND**	10(10)
Shallow	0	20	40	30(15)	40(40)	10(10)
Deep	25	70	10	100(50)	80(80)	7(7)

* Sample taken 10 m from shore

** No data

( ) Verified values

TABLE 3.

Fecal coliform counts for Lake Waubee, the tributaries, and the outlet.

Site	SAMPLE DATES (1981) 4-21	5-26	6-29	7-13	7-27*	8-10
6	30	90	400	2890(590)	30(24)	400(280)
3	20	110	280	4810(960)	ND**	220(160)
5	0	140	390	3300(660)	ND**	380(270)
4	ND**	130	1050	5670(1100)	ND**	240(170)
2	10	200	330	1980(400)	120(100)	560(400)
1	0	90	150	5800(1200)	ND**	80(60)
7	0	40	10	10(2)	ND**	20(14)
Shallow	5	30	20	80(16)	20(16)	30(20)
Deep	0	20	10	20(14)	20(16)	170(120)

* Sample taken 10 m from shore

** No data

( ) Verified values

TABLE 4.

Fecal streptococci counts for Lake Waubee, the tributaries, and the outlet.

Site	4-21	5-26	6-29	7-13	7-27*	8-10
6	100	125	1500	2900(2900)	800(140)	1700(1700)
3	70	210	6000	4800(4800)	ND**	2100(2100)
5	90	260	1100	3300(3300)	ND**	1800(1800)
4	ND**	300	1500	5700(5700)	ND**	1600(1600)
2	160	190	560	2000(2000)	140(24)	640(640)
1	170	150	1200	5800(5800)	ND**	1200(1200)
7	13	15	330	10(10)	ND**	10(10)
Shallow	13	15	20	80(80)	1500(260)	10(10)
Deep	17	11	600	15(15)	3200(540)	20(20)

* Sample taken 10 m from shore

** No data

( ) Verified values

TABLE 5.

Fecal coliform: fecal streptococci ratios for Lake Waubee bacteriological data.

Site	DATE (1981)					
	4-21	5-26	6-29	7-13	7-27*	8-10
6	0.32	0.72	0.27	0.42	0.04	0.24
3	-	0.52	0.05	0.49	ND**	0.10
5	-	0.53	0.35	0.41	ND**	0.21
4	ND**	0.43	0.69	0.39	ND**	0.19
2	0.06	1.03	0.59	0.53	0.14	0.88
1	-	0.60	0.13	0.24	ND**	0.08
7	-	-	0.02	-	ND**	-
Shallow	-	-	-	-	0.01	-
Deep	-	-	0.02	-	0.01	-

* Sample taken 10 m from shore

** No data

TABLE 6.

Standard plate counts (2 day) for Lake Waubee, the tributaries, and the outlet.

Site	SAMPLE DATE (1981) 4-21	5-26	6-29	7-13	7-27*	8-10
6	$>10^4$	$2.5x10^3$	$5.5x10^3$	$7.7x10^3$	$5.3x10^4$	$5.3x10^3$
3	$1.0x10^2$	$6.2x10^2$	$5.1x10^3$	$4.3x10^3$	ND**	$1.6x10^4$
5	$5.5x10^2$	$1.7x10^3$	$1.2x10^4$	$6.2x10^3$	ND**	$3.9x10^3$
4	ND**	$1.2x10^3$	$7.4x10^3$	$6.3x10^3$	ND**	$5.3x10^3$
2	$4.0x10^2$	$1.3x10^3$	$3.8x10^3$	$1.8x10^4$	$5.5x10^2$	$1.1x10^4$
1	$5.0x10^2$	$7.7x10^2$	$1.4x10^4$	$1.3x10^4$	ND**	$3.0x10^3$
7	$5.3x10^3$	$2.0x10^2$	$5.8x10^2$	$4.5x10^2$	ND**	$3.0x10^3$
Shallow	$<10^2$	$1.6x10^1$	$9.5x10^2$	$5.5x10^2$	$4.7x10^3$	$1.7x10^3$
Deep	$8.0x10^2$	$7.2x10^1$	ND**	$7.0x10^2$	$2.5x10^3$	$3.0x10^4$

* Taken 10 m from shore

** No data

TABLE 7.

List of macrophyte species present in Lake Waubee.

Species	1947*	1981#
Chara sp.	X	X
Potamogeton amplifolius	X	-
P. foliosus var. macellus	X	-
P. foliosus var. genuinis	X	-
P. illinoensis	X	X
P. pectinatus	X	X
P. zosterioformis	X	-
P. crispus	-	X
Najas sp.	X	-
Ceratophyllum demersum	X	X
Myriophyllum sp.	X	-
Myriophyllum spicatum	-	X
Vallisneria americana	-	X

* data from Wohlschlag (1950)
# data from this study

TABLE 8.

Zooplankton species found in Lake Waubee.

Species	Winter	Spring	Summer
ROTIFERA			
Kellicottia bostoniensis (Rousselet 1908)		X	
Kellicottia longispina (Kellicott 1879)	X	X	
Keralella cochlearis (Gosse 1851)	X	X	X
Keratella quadrata (Muller 1786)	X	X	X
Notholca acuminata var. extensa (Olofssor 1918)	X	X	
Notholca michiganensis (Stemberger 1976)	X	X	
Lecane luna (Muller 1776)			X
Trichocerca multicrinis (Kellicott 1897)			X
Trichocerca cylindrica (Imhof 1891)			X
Ascomorpha ecaudis (Perty 1850)			X
Asplanchna priodonta (Gosse 1850)	X	X	X
Polyarthra dolichoptera (Idelson 1925)	X	X	X
Synchaeta sp.		X	
Filinia terminalis (Plate 1886)	X	X	X
Pompholyx sulcata (Hudson 1885)			X
Conochilus unicornis (Rousselet 1892)			X
CLADOCERA			
Leptodora kindii (Focke 1844)		X	X
Diaphanosoma birgei (Korinek 1981)			X
Daphnia galeata mendotae (Birge 1918	X	X	X
Daphnia retrocurva (Forbes 1882)	X	X	X
Bosmina longirostris (O. F. Muller 1785)	X		
Eubosmina coregoni (Baird 1857)		X	X
Chydorus sphaericus (O. D. Muller 1785)		X	X
COPEPODA			
Skistodiaptomus oregonensis (Lilljeborg 1889)	X	X	X
Onychodiaptomus birgei (Marsh 1894)	X	X	X
Tropocyclops prasinus (Fischer 1860)	X	X	
Orthocyclops modestus (Herrick 1883)	X		
Diacyclops thomasi (Forbes 1882)	X	X	
Mesocyclops edax (Forbes 1891)		X	X

TABLE 9.

Characteristics of sediment types collected in Lake Waubee on 29 July, 1981. All data are mean values of several determinations. Coefficients of variation on each parameter ranged from 2.79 to 10.5%.

	DW (g cm^{-3})	Water (g cm^{-3})	% Organic
Type 1 (sandy silt)	.4363	.7427	5.94
Type 2 (fine organic silt)	.1431	.9060	18.32
Type 3 (small gravel/sand)	1.2604	.4623	1.87

TABLE 10.

Total Phosphosus concentration in the sediment interstitial water collected at various locations in Lake Waubee on 29 July, 1981.

Sample	Depth (m)	µg P ℓ^{-1}
Transect A		
F	1.0	117.6*
G	7.0	272.5*
L	14.5	2463.5*
X	15.5	3159.7*
A	14.0	1012.1*
K	11.0	2729.3*
R	7.0	409.9*
U	4.0	237.5*
I	0.5	89.7*
Transect B		
Q	0.75	2448.6*
P	3.5	2188.0
D	3.5	1272.1
W	3.75	323.1
V	3.5	305.6
Others		
B	0.5	198.6
C	3.0	78.0
E	0.75	360.0
H	12.0	2713.1

* Mean of three replicate determinations (coefficient of variation ranged from 0.66% to 6.38%).

TABLE 11.

Concentration of Acid-nonlabile sediment bound phosphorus collected at various locations in Lake Waubee on 29 July, 1981.

Sample	Depth (m)	µg P/g Dry Wt. Sed.
Transect A		
F	1.0	86.7*
G	7.0	682.8
L	14.5	1160.3*
X	15.5	928.5*
A	14.0	1060.0*
K	11.0	750.3*
R	7.0	187.8*
U	4.0	223.8*
I	0.5	67.5
Transect B		
Q	0.75	1684.3*
P	3.5	1027.7*
D	3.5	1011.1
W	3.75	305.3
V	3.5	356.2
Others		
B	0.5	17.8
C	3.0	111.8
E	0.75	136.4
H	12.0	836.3

* Mean of three replicate determinations (coefficients of variation ranged from 0.66% to 27.8%).

TABLE 12.

Total sediment phosphorus pool of each depth interval in Lake Waubee.

Strata (ft.)	Total P g (sediment unit)$^{-1}$	Area ($m^2 \times 10^4$)	P Pool ($g \times 10^5$)
0-5	5.529	14.0170	7.7500
6-10	4.884	7.0996	3.4674
11-15	9.417	8.3738	7.8856
16-20	9.214	7.7367	7.1286
21-25	9.010	5.5522	5.0025
26-30	9.873	7.6457	7.5486
31-35	10.736	7.3726	7.9152
36-40	11.599	9.5571	11.0853
41-45	15.261	12.1970	18.6138
46-50	15.200	7.7367	11.7598
50-51	15.200	3.6408	5.5340
Total		91.0200	93.6910

APPENDIX IV

HYDROLOGIC DATA

Fig. 1. Discharge curve for Felkner Ditch.

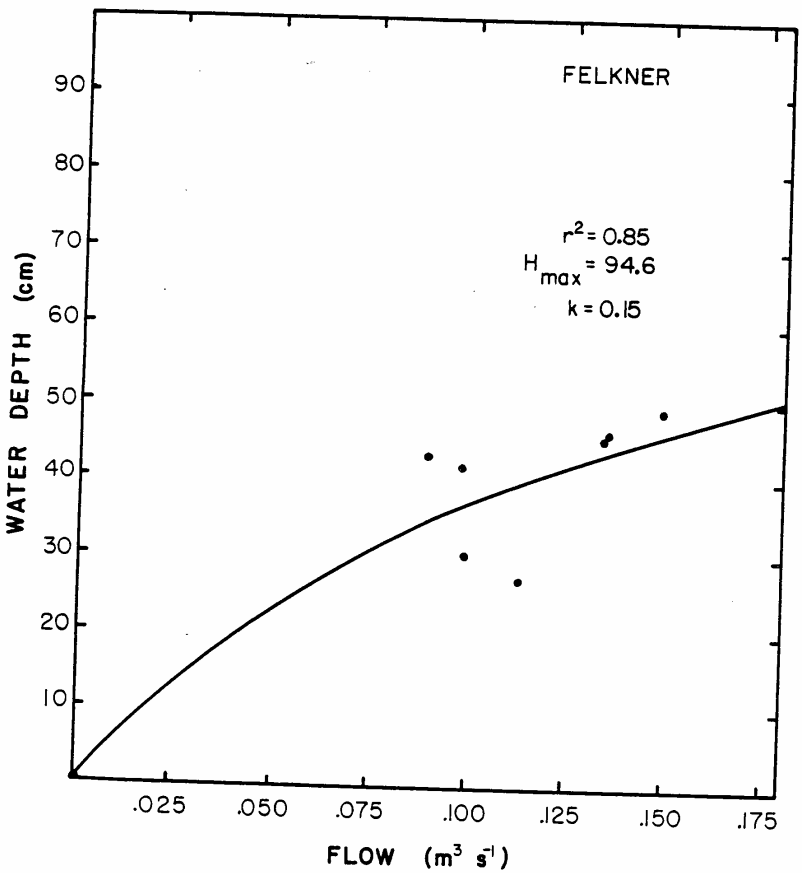

FELKNER
$r^2 = 0.85$
$H_{max} = 94.6$
$k = 0.15$
WATER DEPTH (cm)
90
80
70
60
50
40
30
20
10
.025
.050
.075
.100
.125
.150
.175
FLOW ($m^3 s^{-1}$)

Fig. 2. Discharge curve for Hammond Ditch.

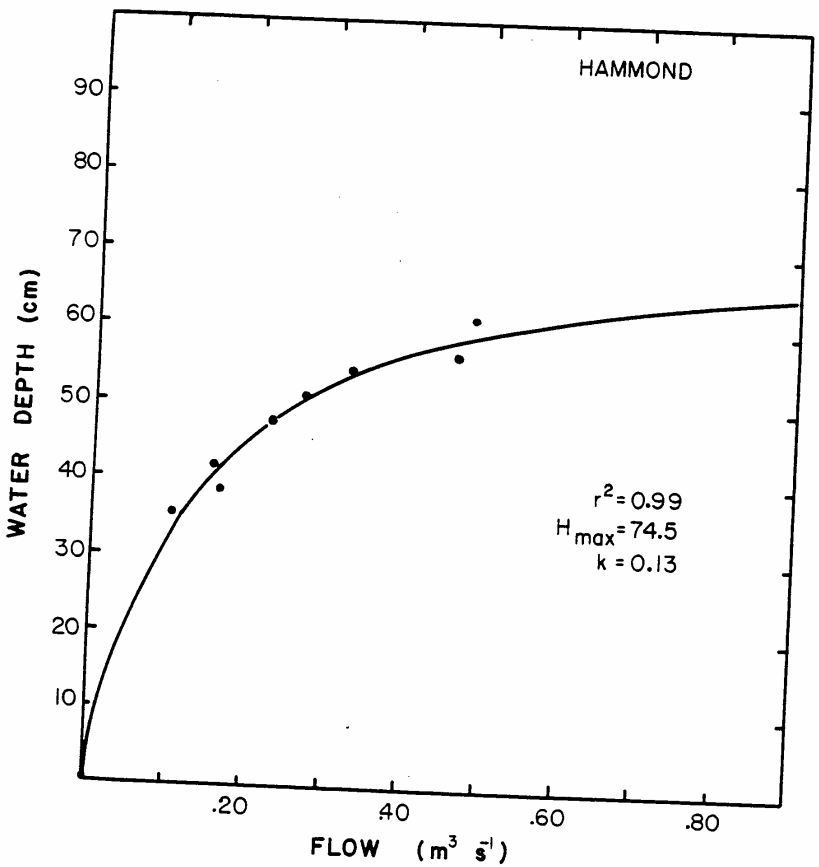

HAMMOND
WATER DEPTH (cm)
90
80
70
60
50
40
30
20
10
.20
.40
.60
.80
FLOW (m³ s⁻¹)
r² = 0.99
H max = 74.5
k = 0.13

Fig. 3. Discharge curve for the Outlet of Lake Waubee.

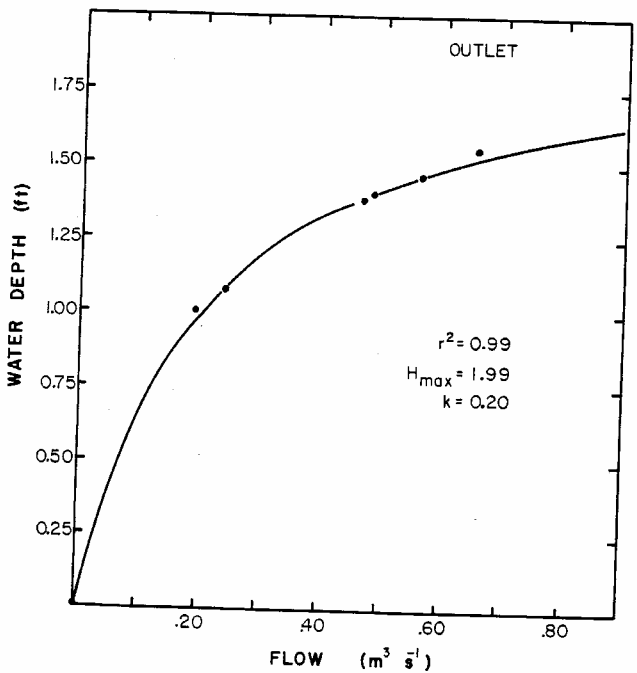

OUTLET
1.75
1.50
1.25
1.00
0.75
0.50
0.25
WATER DEPTH (ft)
r^2= 0.99
H_{max}= 1.99
k = 0.20
.20
.40
.60
.80
FLOW (m^3 s^{-1})

TABLE 1.

Precipitation data for Lake Waubee.*

Month	Total Precipitation (in)
Sept. 1980	4.42
Oct. 1980	1.73
Nov. 1980	0.92
Dec. 1980	2.98
Jan. 1981	0.17
Feb. 1981	1.97
Mar. 1981	0.25
Apr. 1981	8.82
May 1981	5.84
June 1981	9.25
July 1981	3.95
Aug. 1981	3.29
Total	43.59

* Data from National Weather Service Station, Warsaw, Indiana.

APPENDIX V

PREDICTION OF LAKE WAUBEE PHOSPHORUS CONCENTRATION USING MODELING AND ERROR ANALYSIS BASED UPON LAND USE INFORMATION

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PREDICTION OF LAKE WAUBEE PHOSPHORUS CONCENTRATION USING MODELING AND ERROR ANALYSIS BASED UPON LAND USE INFORMATION

CONSTRUCTION OF MODEL

Reckhow and Simpson (1980) have developed a mathematical model for estimating the annual average phosphorus concentration for lakes. The model is based upon Reckhow's (1979) work with 47 north temperate lakes sampled as part of the EPA's National Eutrophication Survey (NES). The basic model is:

$$P = \frac{L}{V_s + q_s} \qquad (1)$$

where P = phosphorus concentration (mg l^{-1}), L = areal phosphorus loading (g m^{-2} y^{-1}), V_s = apparent settling velocity of phosphorus (m y^{-1}), and q_s = areal water loading (m y^{-1}). From analysis of the NES data, it was found that equation (1) could be rewritten as:

$$P = \frac{L}{11.6 + 1.2\ q_s} \qquad (2)$$

Hence, mean annual phosphorus concentration for Lake Waubee can be predicted by determining areal phosphorus loading, L, and areal water loading q_s. (Note: The limitations on this model, as discussed by Reckhow and Simpson, did not impair its use for Waubee).

The areal water loading, q_s, is determined from the following equation:

$$q_s = \frac{Q}{A_o} \qquad (3)$$

where Q is the inflow water volume (m^3 y^{-1}) and A_o is the lake surface area (m^2). The inflow water volume, Q, is determined as follows:

$$Q = (A_d \times r) + (A_o \times Pr) \qquad (4)$$

where A_d is the watershed area (m^2), r is the total annual unit runoff (m y^{-1}), and Pr is the annual net precipitation (m y^{-1}).

Parameters used in the calculations of q_s for Lake Waubee were:

$A_o = 0.7585 \times 10^6\ m^2$ (direct calculation from planimetry of lake map)

$A_d = 36.6779 \times 10^6\ m^2$ (personal communication I.D.N.R.)

$r = 0.2921\ m\ y^{-1}$ (Reussow and Rohne, 1975)

$Pr = 0.9144\ m\ y^{-1}$ (Reussow and Rohne, 1975)

q_s becomes:

$$q_s = \frac{(36.6779 \times 10^6 \times 0.2921) + (0.7585 \times 10^6 \times 0.9144)}{0.7585 \times 10^6}$$

$$= 15.0391\ m\ y^{-1} \qquad (5)$$

This high areal water loading is due to the unusually large ratio of watershed area to lake surface area ($A_d/A_o = 50$).

The areal P loading to Lake Waubee was found using the formula:

$$L = \frac{M}{A_o} \qquad (6)$$

where M is the total mass loading of P ($kg\ y^{-1}$). The total mass loading of phosphorus to the lake was found by summing the contributions from each identifiable source in the lake watershed. For our modeling purposes, the following sources were identified: forested land, agricultural land, urban land, precipitation, dry fallout, and septic tanks. No point source input was included in the model. We expressed mass loading, M, as:

$$M = (E_f \times A_f) + (E_{ag} \times A_{ag}) + (E_u \times A_u) + (E_p \times A_o) + (E_d \times A_o) + (E_{st} \times \text{number of capita-years} \times (1\text{-}SR)) \qquad (7)$$

where

E_f = export coefficient for forest ($kg\ 10^6\ m^{-2}\ y^{-1}$)

A_f = area of forest land (m^2)

E_{ag} = export coefficient for agricultural land ($kg\ 10^6\ m^{-2}\ y^{-1}$)

A_{ag} = area of agricultural land (m^2)
E_u = export coefficient for urban land (kg 10^6 m^{-2} y^{-1})
A_u = area of urban land (m^{-2})
E_p = export coefficient for precipitation (kg 10^6 m^{-2} y^{-1})
A_o = area of lake surface (m^2)
E_d = export coefficient for dry fallout (kg 10^6 m^{-2} y^{-1})
E_{st} = export coefficient for septic tanks impacting lake (kg capita-year $^{-1}$ y^{-1})
No. capita-years = total septic systems impacting lake
SR = soil retention coefficient (dimensionless)

Selection of the appropriate values for the export coefficients in equation (7) was a difficult task. Reckhow and Simpson (1980) have compiled published data into a table consisting of low, high, and middle (most-likely) estimates for the export coefficients. These are summarized below: (all as kg P 10^6 m^{-2} y^{-1}, except septic which is kg capita-yr^{-1})

	Forest	Agriculture	Urban	Precipitation	Septic
high	45	300	500	60	1.8
middle	20	105	190	35	0.6
low	2	10	50	15	0.3

Watershed usage areas with their sources in parentheses are:

$A_f = 2.6305 \times 10^6\ m^2$ (L.R. Staley, S.C.S., personal comm.)
$A_{ag} = 34.0474 \times 10^6\ m^2$ (" " " " " ")
$A_u = 0$ (" " " " " ")
$A_o = 0.7585 \times 10^6\ m^2$ (from planimetry of topographic map)

The number of capita years was calculated as:

$$\text{Number of capita-years} = \text{average \# persons per unit} \times \frac{\text{\# days spent at unit per year}}{365} \times \text{\# units} \quad (8)$$

Data provided by the Lake Waubee Lake Association yields the following estimate:

Permanent: $(4 \times \frac{365}{365} \times 68) = 272.00$
Temporary: $(4 \times \frac{150}{365} \times 44) = 72.33$
Camp Mac: $(218 \times \frac{90}{365} \times 1) = 53.75$
Total capita-years $= 398.08$

Using the low, high, and most-likely values for the export coefficients, the following estimates of mass loading to Lake Waubee were found:

$$M_{high} = (45 \times 2.6305)+(300 \times 34.0474)+(500 \times 0)+(60 \times .7585)+(80 \times .7585)+(1.8 \times 398.1 \times 1.0)$$
$$= 11{,}155.4 \text{ kg P } y^{-1} \quad (9a)$$

$$M_{ml} = (20 \times 2.6305)+(105 \times 34.0474)+(190 \times 0)+(35 \times .7585)+(80 \times .7585)+(.65 \times 398.1 \times 1.0)$$
$$= 3{,}973.6 \text{ kg P } y^{-1} \quad (9b)$$

$$M_{low} = (2 \times 2.6305)+(10 \times 34.0474)+(50 \times 0)+(15 \times .7585)+(80 \times .7585)+(.3 \times 398.1 \times 1.0)$$
$$= 537.2 \text{ kg P } y^{-1} \quad (9c)$$

In all cases, a soil retention coefficient of 1.0 was used (this is a worst case scenario which assumes that 100% of P from the septic tanks reaches the lake). Plugging the values obtained from equations (9a-c) into equation (6) yields loading estimates of:

$$L_{high} = \frac{11{,}155.4}{758{,}500} = 14.71 \text{ g } m^{-2} y^{-1} \quad (10a)$$

$$L_{ml} = \frac{3{,}973.6}{758{,}500} = 5.24 \text{ g } m^{-2} y^{-1} \quad (10b)$$

$$L_{low} = \frac{537.2}{758{,}500} = 0.71 \text{ g } m^{-2} y^{-1} \quad (10c)$$

These loading estimates were used along with the value of q_s from equation (5) to provide a prediction of the in-lake P concentration in Lake Waubee by applying equation (2):

$$P_{high} = \frac{14.71}{14.6 + 1.2\ (15.04)} = 0.496 \text{ mg } \ell^{-1}$$

$$P_{ml} = \frac{5.24}{11.6 + 1.2\ (15.04)} = 0.177 \text{ mg } \ell^{-1}$$

$$P_{low} = \frac{0.71}{11.6 + 1.2\ (15.04)} = 0.024 \text{ mg } \ell^{-1}$$

The uncertainty of these predictions was estimated by non-parametric first-order error analysis as detailed by Reckhow and Simpson (1980). Accordingly, the 80% confidence limits on the most-likely in-lake P concentration become:

$$0.0435 \text{ mg } \ell^{-1} \leq P \leq 0.4278 \text{ mg } \ell^{-1}$$

VERIFICATION OF MODEL

The estimated value of q_s from calculations was 15.039 m y^{-1}. The measured value of q_s for the year beginning September 1980 through August 1981 was 10.984 m y^{-1}. This overestimation of water loading is primarily attributed to the watershed runoff component. Measurements indicate that (A_d x r) was overestimated by 30% in the model calculations. Causative factors are unclear, but may be related to the extensive drainage network in the area surrounding the lake. Artificial drainage ditches may channel water away from the lake, making the effective watershed area somewhat smaller than the measured watershed area. This could account for a large portion of the discrepancy.

The measured mass phosphorus loading, M, was 583.8 kg P y^{-1}. This value falls between the low (537.2 kg P y^{-1}) and most-likely (3973.6 kg P y^{-1}) estimates of mass loading. Since most of the P entering the lake originated in the watershed export compartment, an overestimate of the effective watershed area as mentioned above could account for the large value of m_{ml}. The measured areal P loading (equation 10c, adjusted for M) was 0.77 g m^{-1} y^{-1}.

The predicted mean annual in-lake phosphorus concentration (P) using the measured values of L (0.77 g m^{-2} y^{-1}) and q_s (10.984 m y^{-1}) was calculated using equation 2 as:

$$P = \frac{0.77}{11.6 + 1.2(10.984)}$$

$$P = 31.1 \text{ µg } l^{-1}$$

The measured mean annual phosphorus concentration averaged over all depths and dates, was 29.7 µg l^{-1}. Comparison of the two figures reveals remarkable agreement, the measured value merely 4.5% lower than the predicted. This indicates that the best fit form of equation 2 works very well in modelling the response of Lake Waubee to a given nutrient and water load. This relationship is important in predicting the response of Lake Waubee to various hypothetical reductions in phosphorus loading. Implications are discussed in the management plan section (Section IX).

APPENDIX VI

PHOSPHORUS COMPARTMENTALIZATION OF LAKE WAUBEE

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All of the phosphorus retained in lacustrine systems becomes incorporated into one of the following major phosphorus pools:

1. the fish biomass
2. the macrobenthos biomass
3. the macrophyte biomass
4. the seston - includes living and dead particulate suspended matter (ie. zooplankton, phytoplankton, bacteria, etc.)
5. dissolved phosphorus in the lake water
6. the sediments

The activity of biotic and abiotic factors in the lake ecosystem cause a continual flux of phosphorus from one pool to another. The differential response of various biotic populations to changing ambient environmental conditions induces short-term variation in the size of these pools. An overall homeostatic condition subject to temporal fluctuations prevails, and unless interrupted, maintains a relatively constant amount of phosphorus in each of the biotic compartments on a year to year basis. Very gradual increases do occur, however, as the lake undergoes the process of eutrophication. Typically, most of the phosphorus entering the lake system eventually reaches the sediment pool.

Estimates of the relative magnitude of the various phosphorus compartments of Lake Waubee are given in Table 1. The derivation of these values are discussed in the following material.

The fish standing stock in Lake Waubee was estimated to be 336.24 kg ha^{-1} (Stu Shipman, I.D.N.R., personal communication). The

live weight phosphorus content of fish is 1.99% (Applegate 1971). The fish community, therefore, contains 6.69 kg P ha^{-1}. This value times the surface area of the lake yields a total phosphorus pool of 507.2 kg P in the fish community.

Macrobenthos biomass estimates were taken directly from an intensive study of Lake Waubee by Wohlschlag (1950). Based on his data, the average benthic biomass was calculated to be 764.4 mg dry weight m^{-2}. Insects have an average dry weight phosphorus content of 1.0% (Spector 1956). This data allows calculation of an areal macrobenthic phosphorus content of 7.64 mg P m^{-2}. The total amount of phosphorus in the macrobenthos pool is therefore found by multiplying the areal phosphorus content by the surface area of the sediments (9.102×10^5 m^2) to yield 6.95 kg P.

Macrophyte biomass and tissue nutrient content were monitored during the course of the study (see Figs. 24 and 25 of Appendix III). The largest standing stock of aquatic vascular plants occured on 11 June, 1981. The amount of phosphorus in the plant tissue nutrient pool at this time was calculated to be 10.82 kg P. This value was selected for all subsequent analysis, and represents the maximum expected phosphorus content in this compartment.

The particulate phosphorus in the seston and the dissolved phosphorus in the lakewater were collectively quantified in the total phosphorus analysis of in-lake water samples. The weighted average phosphorus concentration, calculated over all depths and sampling dates, was 29.65 µg ℓ^{-1}. This value was multiplied by the lake volume (6.017×10^9 ℓ) to estimate the magnitude of this phosphorus

pool. Results of this analysis indicate that 178.4 kg P are contained in these combined phosphorus compartments.

The sediment phosphorus pool was directly quantified as part of the overall investigation (see section VI). This compartment contained 9,369 kg P, and overwhelmingly represented the greatest store of phosphorus in the entire system.

TABLE 1.

Phosphorus compartments of Lake Waubee.

Compartment	kg P	% of Total
Fish	507.2	5.0
Macrobenthos	6.95	0.1
Macrophytes	10.82	0.1
Seston/dissolved P	178.40	1.8
Sediments	9369.0	93.0